Experiences from Teaching Master level Course in Research Methods in Systems of Systems Engineering

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Experiences from Teaching Master level Course in Research Methods in Systems of Systems Engineering

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***Abstract*— The paper summarizes the challenges and experiences from a course in research methods for systems engineering master's students. This course is a preparatory course for the final master's project. Each student selects a topic to investigate in the course. Most of these topics fall into the category of systems of systems engineering.**

This paper investigates the underlying course contents, teaching method, evaluation, and feedback to/from students. We learnt/noticed that students had challenges in writing the research questions and framing the research design. To overcome these challenges, we demonstrate a systematic procedure by offering a "research framework".

Keywords—research methods, line of reasoning, research design, feedback, experiences, systems of systems

I. Introduction

The University of South-Eastern Norway (USN) has master's programs in Systems Engineering (SE) and in Industrial Economy with Systems Engineering. The students in these master's programs do, at the end of their study, a master project of 30 credits in the European Credit Transfer and Accumulation System (ECTS). This is the equivalent of half a year full-time work. Students have to show in this project that they can apply some of the theory in practice. Furthermore, they have to evaluate the theory that they apply in an academic way. To produce quality research work, it is important that they understand the methodology and application of different scientific methods.

Challenge in researching methods for development of systems of systems (SoS) is that these methods cover a broad set of disciplines, ranging from hard technical (e.g. performance) to socio-political (e.g. acceptance). In addition, projects using these methods have a variety of contexts, stakeholders, systems, technologies et cetera. This variety triggers the need that each research project has to select suitable research methods for that specific research question and context. There are no dominating research methods that will guide the students, during their research. Rittel and Webber [1] explain that in these wicked problems there is no holy grail.

The main purpose of this new course in Research Methods (for systems of systems engineering) is to prepare the students for their master's project. The authors developed and taught this course at USN for the master's students in Industrial Economy with Systems Engineering. We plan to offer this course to the students in the Systems Engineering program as well.

In this paper, we describe our experience from the course and set out to answer the question: What are the underlying course contents, teaching method, evaluation, and feedback to/from students? We present a list of topics selected by students for doing their research, showing the relation with SoS engineering.

The structure of this paper is as follows: First, we present the challenges of research methods in a SoS context, and the research methods that are common in this setting. Second, we describe the course in terms of learning objectives and learning outcomes and introduce the teaching format of the course. Then we describe the student activities, assessment, and feedback. Lastly, we summarize the course evaluation and the student feedback before offering our conclusions and discussing future research.

II. Research Methods and Challenges in Systems of Systems Research

Systems of Systems engineering takes place in commercial companies resulting in SoSs that we deploy, use, and depend on in practice. The industry involved in developing SoSs has a pragmatic interest in methods and tools that help them in developing SoSs. The academic community has a fundamental interest in methods and tools. What principles drive the methods? How do methods fit in the existing knowledge? Muller in [2] explores the gap between the industrial and academic perspectives, as Fig 1 shows.

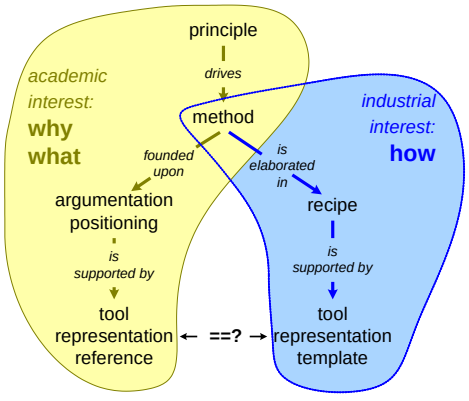

Fig. 1. Industrial and academic interests in methods and tools differ [2]

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In [3], Muller provides a Meta-level model positioning these interests; see Fig 2. Meta^0 is the system-of-interest in its context, e.g. the SoS and its organizational and life cycle context. This is the normal world for industrial people. At the end of the day, they need to deliver well-functioning systems to their customer.

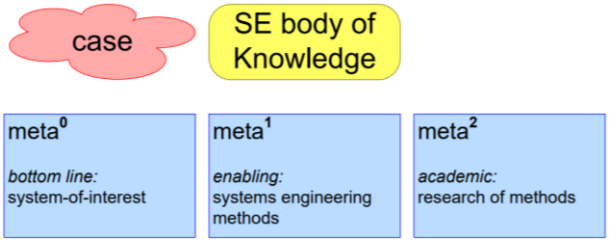

Fig. 2. Meta level perspectives, simplified from [3]

The practitioners in industry need methodologies (methods, tools, formalism, techniques) that enable them to develop the system-of-interest. They can find these methodologies in the bodies of knowledge, such as the SEBoK [4]. Meta^1 is the realm of the enabling methodologies. Academics have an interest in creating and evolving methodologies. Practitioners and researchers share an interest in methodologies.

Academic researchers have a scientific interest to validate methodologies with academic rigor. Meta^2 is the way we research the methodologies in Meta^1. Good methodologies are methodologies that enable practitioners doing their work in Meta^0. Research of the methodologies requires application of these methodologies in practice.

Common approaches for the research of methods are:

- Action Research [5]
- Participatory Action research [6]
- Case Studies [7]
- Design Research Methods [8]
- Industry as Laboratory [9]

These research methods overlap in their approach. The common denominator is that these methods facilitate research in the practitioners' field. Falk and Muller [10] evaluated 10 years of master project research at USN systems engineering, where the students were using these research approaches.

III. Course Description

The learning and teaching activities of this course include in-class teaching, in-class student activities, pre-reading materials, and home assignments. The students gather for five workdays, organized in 2+2+1 day format.

A. Objectives and Learning outcomes

The course has the following objectives:

- Enable students to clearly explain the line of reasoning for doing the research
- Enable students to formulate the research questions so that they can design and execute the research
- Teach students techniques for effective literature reviews
- Make students confident in research design. This includes selecting appropriate research design and data collection requirements, analyzing data uncertainty, and validating the research outcome.
- Provide insight to research ethics
- Establish the mind-set to do research
- Enable the students to design and prepare their project execution phase
- Train the students in academic writing of a conference/journal paper

At the end of the course, the students should have the following learning outcomes:

- be able to conduct research work in accordance with scientific standards and principles of research ethics
- can analyze, interpret and critically assess the results available in scientific literature

B. Course Framework

Fig. 3 shows the framework that we use in the course. The first step is to shape the line-of-reasoning. The line of reasoning is a common thread throughout the research definition and execution. The following section describes this in more detail.

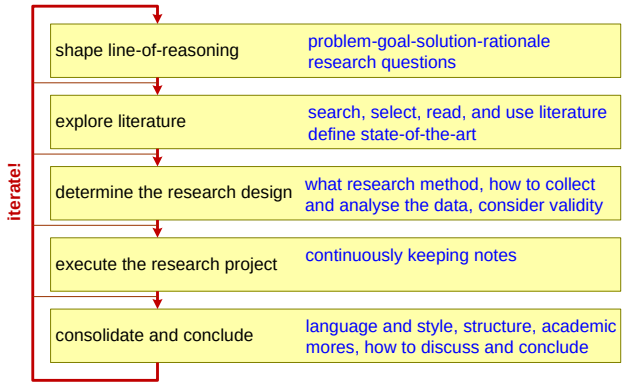

Fig. 3. The research Framework

The second step is to explore literature. That is, explore the state-of-the-art knowledge about the problem and its solutions. Always, there exists a state of dilemma in finding the relevant literature from huge pool of academic publications. Students shall develop a competency in coping with this challenge by interacting with the teachers.

The third and final major step in the research methods course is determining the research design. What research method fits the research questions and the context? How to collect and analyze data? What validity can we expect from the results?

During the course and later in the execution period of the master project the students shall re-visit the steps presented in Fig. 3 multiple times. In each iteration, the line-of-reasoning will improve, the literature will become more relevant, and the research design becomes more concrete.

A major learning objective of the master project is to develop the ability to explore the solution and to find and adapt appropriate skills and knowledge. We need to get

students into a mindset that they dare to explore and learn, so that they can develop this competence.

C. Defining the master project through a Line-of-Reasoning

The line of reasoning is essential to our master project definition. The faculty members loosely define the master project topics and the student is free to select the master project topic based on interest. Muller designed the Line of Reasoning based on experience with students working part time in industry [11]. The line of reasoning consists of six areas: problem, goal, proposed solution, rationale, research questions, and research approach. Muller formulates the areas in six questions where the first three bullets are the foundation of the master project proposal; the next questions form the foundation of the academic approach:

- What problems/challenges does the company experience or foresee that triggers this research?
- What is the goal when solving this problem?
- What proposed solution(s) address these problems
- What is the rationale for this solution? Why does your research select this specific subset of solutions?
- What do we want to learn via the research? This results in a set of research questions, often one main question, and a set of sub-questions.
- what approach will allow you to collect data, do analysis, and eventually evaluate the effectiveness of the approach or solution (within the master project constraints)

We use the line of reasoning in the research methods course to guide the students in developing their topic into specific research questions. The student starts with exploring the problem space using literature and by discussing with the topic owner. The topic owner is a faculty member and sometimes supported by additional external parties like companies and organizations. When exploring the problem space we ask the students to look for the pain points. These are the areas where we observe difficulties typically showing as inconsistencies or uncertainties. By exploring the pain points, we challenge the common body of knowledge and identify problems in the current situation.

Table *1* presents the topics selected by students for the research in SoS. The energy and storage areas combine many systems, e.g. producing systems, transmission, and distribution, trading, stabilizing, storage, and consuming systems. The business, education, and design and validation areas may address single systems. However, most innovations nowadays are in capabilities emerging from the interaction of multiple systems. Logistics is another area that is SoS by nature.

The next area is to explore the solution space. We ask the students to look at the Systems Engineering body of knowledge and look for alternative Meta[1] topics that can help solve the problem. We encourage the students to think about what they will do during the master project. Only creating artifacts to provide a solution to a problem is not sufficient. They will also need to evaluate and validate the Systems Engineering method and gather sufficient evidence to build the SE body of knowledge. This is the Meta[2] academic level (see Fig. 2). The final three areas in the line of reasoning summarize the academic approach and consist of defining the goal of the research, the research questions, and the research design. This is a direct result of exploring the three Meta levels.

Table 1: A list of SoS topics selected by students for doing the research.

SoS Area	**Topic name**
Energy and storage	Conceptual Modeling of Seasonal Energy Storage for Intermittent Renewable Energy Sources (2 projects)
	Solar Photovoltaics Investments (2 projects)
	Inspection framework for wind farms
	Interaction model for parties and systems in a future flexible distribution of power
Business	A Framework to Improve Cooperation Between Incubator and Entrepreneur
Education	Is blended learning effective for master programs in systems engineering and industrial economy?
Logistics	Digitization of document handling within industrial logistics (2 projects)
Design and validation	in early phases, among others in subsea oil and gas (2 projects)

When explaining the difference in Meta levels we find it useful to discuss with students the different approaches to methods, techniques, and tools between academia and practitioners. In the industrial mind-set, the focus is on the application. The academic mindset is on what and why, and the positioning of a tool in a frame of reference. Students in Systems Engineering need to explore both the application of the methods in the industrial/practical context as well as the scientific founding of the methodology; see Fig. 2. This aspect is somehow different from more traditional engineering master projects where the focus can be to explore new applications of a given combination of engineering techniques within an engineering field.

D. Exploring the Literature

In exploring the literature, it is rather easy for students to get lost in what is required in the problem context.

Systematic literature reviews require structure. The students learn to use research databases and libraries during their bachelor education. However, the students are not necessarily good at structuring the literature surveys required for research. We found that our focus was too light, discussing mainly the search techniques of research data. We found that the students missed the point of exploring literature systematically. In the future, we need to develop additional approaches to ensure that the students develop an attitude to search the available literature from multiple perspectives and in multiple iterations.

E. Research methods

Engineering students are used to measurements and calculations, hence the systems engineering field can be soft and difficult to comprehend. Many students categorize research into quantitative vs qualitative methods and they are sometimes concerned with the lack of hard data in their research design. Most of the existing research methods

courses teach statistics predominantly. However, it is important to know how to obtain/collect the required data, later it follows how to interpret, analyze and report the collected data. Research in SoS means often research in soft [12] and complex [13] systems. The amount of data is then so low that statistical analysis mostly shows that it is insufficient for a statistical significant conclusion.

We find Muller's spectrum of research methods particularly useful to help students understand the difference between the soft and the hard evidence [11]. Students exposed to the wide spectrum of research methods shown in Fig. 4, find it easier to understand the need for open interviews to explore the problem and solution space of their system of interest. The students are encouraged to look for methods within the full spectrum and to design their research using a variety of methods during multiple iterative loops.

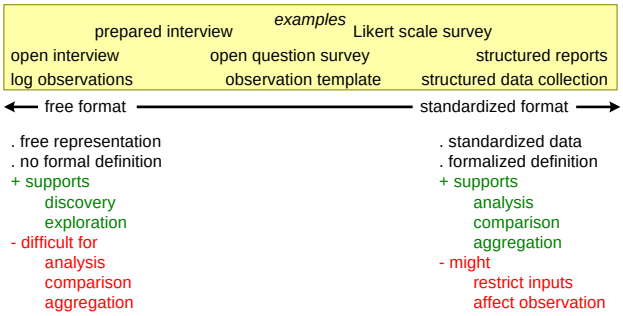

Fig. 4. Spectrum of research methods; simplified after [11]

As shown in Fig. 4 the spectrum of research methods ranges from free format methods to standardized format methods. A free format enables discovery and exploration. However, a free format without a formal definition is more difficult to analyze, compare, and aggregate. Standardized formats with formalized definitions support analysis, comparison, and aggregation. However, this method may lose anything outside of the definitions and therefore the formalized definition can affect the observations.

This format axis applies to many aspects, e.g. the way researchers capture observations, the way they elicit information from stakeholders, or the way they capture and analyze the problem itself.

IV. Student Activities and Assessment

Constructive alignment [14] [15] founds the basis of the pedagogics of this course. Thus, the learning outcomes are linked to teaching and learning activities as well as to assessment. The assessments are primarily summative, with the final assessment being also normative.

A. *Student-active learning*

The systems engineering program is using the pedagogic approach where we strive to get students actively involved with the learning material. The limited time spent for lecturing is focused towards student learning.

Students work in this course on their own case that is the topic of their master's project. They do this work as in-class assignments, homework, and as a final submission. The in-class assignments have several specific questions for each of the steps in Fig. 3. The homework assignments are elaboration and consolidation of the in-class assignments. In the final submission, the students are capturing the results in the form of an academic paper. The teachers grade the final submission.

B. *Summative assessment*

The teachers provided the students with direct oral feedback during the in-class work and written feedback related to the homework. This feedback helps in scoping of the master project and shaping of the line-of-reasoning.

The research question is one of the items in the line-of-reasoning, and an important vehicle for research in Systems of Systems Engineering. The students are asked to express the research questions in an active voice. The teachers let the students determine the subject of the action. Active voice makes explicit who is acting (e.g., Instead of stating that requirements impose the solution, stating "the principal imposes solutions in the requirements formulation"; when the designers impose solutions, then we have a different problem). The teachers also guide the research questions from closed to open statements (in terms of measurable attributes/claims).

C. *Rubrics for assessment of final submission*

The rubrics for assessing the final submission of the course work are:

- Line of reasoning
- Literature
- Research design
- Academic writing
- Overall coherence and consistency

These rubrics are in-line with the applied research framework as shown in Fig. 3.

The teacher provided written and detailed feedback on the submitted assignment in the form of a conference paper of max. 15 pages. Written feedback included general comments on the overall level of the paper, how well the paper was formulated, and the level of coherence. In addition, the teachers gave specific comments related to line of reasoning, literature review, research design, execution plan, and book plan.

V. Course Evaluation, Feedback from Students

We collected feedback from the students during the course and after the course.

A. *Students feedback during the course*

All course days end with the "benefits and concerns" session. In this session, we ask the students to write on stickers their perspectives on the course benefits and concerns and post them on large flip overs, see Fig 5. The teachers group the input and address the main topics in plenum before the close of teaching day. We find this approach meaningful for two reasons; a) the students are free to note their concerns without exposing their opinions, b) the teachers get the immediate feedback of the learning outcome and can clarify and adjust as needed. We find this immediate feedback vital to the continuous quality development of our teaching.

Typical concerns that students note are lack of time, challenge to find required and relevant information and literature, difficult to formulate the line-of-reasoning or to identify stakeholders, information overload and confusion, and the course being too abstract.

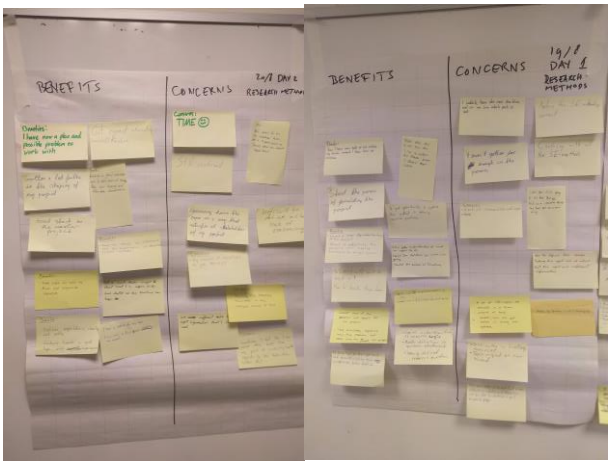

Fig. 5. Benefits and concerns at the end of each course day

B. Student feedback after the course

We received mixed feedback from the students after the course. The students' representative collected the students' feedback and reported to the teachers.

1) Confusion, Lack of clarity

The students were confused when different teachers gave different instructions in conducting various tasks; in the feedback, they mentioned this as "lack of consensus". Here we suggest that, students should learn to cope with confusion. The teachers recognize the challenge of internal alignment when multiple teachers are teaching the same course. Because teachers offer different perspectives, it is crucial that all teachers are present at all lectures. This helps the teachers understand areas of misalignment and helps to guide the students when confusion arise. For students who will work in SoS development, it is adamant that they learn to cope with such variation of inputs and interpretations.

The students asked for more elaboration of the homework description. In their opinion, they did not get enough information to know what the teachers expected. From the teacher perspective, we provide brief and relatively open questions on purpose. In the master project, the students have to show their ability to do research independently. Hence, they have to learn to define their own direction. We need to gets students into a mind-set that they dare to explore and learn, so that they can develop this competence. Students do not have to do this entirely on their own. The research methods course help them learn this, while during their master project, they will get supervision. As teachers, we conclude that we have to stimulate students to interact more with teachers, academic supervisors, and stakeholders.

2) Course structure

The students indicated that they found the process of establishing research question confusing and unstructured. We recognize this problem. Unfortunately, finding a good research question is tough and at the core of doing good research. We speculate that adding a running case to the course, independent of their individual topic, may help to serve as learning vehicle. As in the previous point, students should use the teaching resources sufficiently; first they have to try themselves, and then start to interact with the teachers or other stakeholders to get the research questions clarified.

The academic writing was at the end of the course. Students suggest to move this to the beginning, since they then can use that in their homework assignments, and get earlier feedback on the academic writing from the teachers. They also suggest to ensure that the homework assignments and the final submission are building on each other; the homework assignments should contribute to the final submission. That was the intent, however, we can clearly improve this.

3) Unnecessary lectures

The students indicated that the literature search lecture was known to them from their bachelor studies. If students lack this as background, then the curriculum should offer this at the beginning of the program.

4) Late information

The students got the assessment rubrics during the last course day. That is too late; this information should be available from the beginning of the course.

C. Teacher Experiences

Students had challenges in coping with the academic writing (both linguistic and structure) part, we suggest to include this step as a continuous process in homework assignments and during the course days.

We need ways to help students in coping with these abstract topics when conducting research. We consider introducing a running case, independent of the individual research projects, where the class can collectively apply the methods.

It is challenging to select a research method suitable for doing research in SoS engineering. The students have so many new aspects to learn, e.g. the system of interest and its context ($Meta^0$), the literature on suitable methods ($Meta^1$), and the challenges of SoS methods research ($Meta^2$) that converging to a suitable method, and envisioning suitable data collection and analysis methods, is really challenging. Hopefully, a running case will alleviate this challenge somewhat.

We can compare this group of students with the systems engineering students of the past 10 years. These systems engineering students follow 3 preparation 2-hour workshops plus a 4-hour workshop on academic writing. The systems engineering students have been working in their company for 2 years when they start these workshops, which is not the case for most industrial economy students. In general, the systems engineering students have an easier job in shaping and scoping their topic, since they know the context better. We observe that the students that participated in this research method course have a better starting point from literature perspective. We know from past master projects, that students hit the problems of a poor line-of-reasoning when they start writing [10]. We expect that this effect is less when students have gone through this research methods course; the final submissions give an early indication that they have a good starting point for the master project execution.

Our main improvements are therefore:

- Restructure the order, so that academic writing, the explanation of the homework assignments and their coherence, and grading criteria are in the beginning.
- Including a running case in the course that teams in the class can work on during the course days. This running case should address the line of reasoning, research questions, research design,

literature survey and critique, and some execution of the research.

- Unfreeze students even more from the paradigm of exercising well-known problems and solutions. A major learning goal of the master project is to develop the ability to explore the solution and to find and adapt appropriate skills and knowledge. We need to gets students into a mindset that they dare to explore and learn, so that they can develop this competence.
- Stimulate students to interact more with teachers, academic supervisors, and stakeholders. Explain and train students in coping with (seemingly) conflicting perspectives.

VI. Conclusions

The research framework we presented in this paper helped students in their preparations to perform research on systems of systems engineering topics.

We find that iterative loops of the research framework in combination with the line of reasoning are helpful mental models during the project definition phase.

The line of reasoning is essential in developing the master project. The line of reasoning allows the student in exploring the Meta levels and gain understanding of the difference between the practical world and academia.

Research is an iterative process. We find that the research methods course helps to develop the student's understanding of the iterations required to execute a successful master project. The iterative loops described in the research framework provide us with effective models to guide the students in their research design.

Future research

The students that followed this course are now executing their master project. The desired effect of this course is that they can execute their master projects more smoothly. Future research has to evaluate the effect. More evaluations of future instantiations of the course will lift the evaluation from being just one incident.

Acknowledgment

We thank the Research Methods class of 2019 for being our guinea pigs.

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