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Using A Spiral Approach To Facilitating Engineering Research And Education In Real Industry Settings

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Using a spiral approach to facilitate engineering research and education embedded in real industry settings

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ABSTRACT

Engineering research and education is often done in collaboration with industrial partners through the Industry as Laboratory (IaL), and Challenge-Based Learning (CBL) paradigms. However, its findings are not always adopted, despite the use of well-established and rigorous research methodologies. Academia employs oftentimes extensive and time consuming analyses, while industry operates in smaller cycles with tangible intermediate results. This can lead to the industry losing interest in the research. The Spiral Approach for Systems Engineering Research (SASER) is an approach that aims to mitigate that risk. This can have a twofold benefit in the industry remaining interested, but also the researcher staying motivated. To apply this approach in practice and receive feedback from a broader audience of people we created the SEFI 2023 workshop entitled: “Using a spiral approach to facilitate engineering research and education embedded in real industry settings”. This workshop has the objective of discussing best practices when conducting engineering education and research in collaboration with industry. To achieve the planned learning outcomes, the workshop activities will follow a cycle of learn=>apply=>reflect on provided specific case studies that are developed in order to allow the application of SASER. The workshop was attended by 8 participants that were split into 2 groups of 4 people (the 2nd group further decided to split further into a group of 3 and one individual). The results of

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the case studies and the reflection of the participants in the workshop indicate a clear potential for SASER and are promising for further research and development.

1 WORKSHOP MOTIVATION & LEARNING OUTCOMES

Engineering research and education is often done in cooperation with industry. This is because the practical effectiveness of engineering methods and techniques in industry can only be evaluated in such settings (Falk and Muller 2019). Unfortunately, research findings in this context often fail to be adopted by industry (Muller 2005), despite using a thorough and rigorous research methodology like the Design Research Methodology (Blessing and Chakrabarti 2009) and the Design Science Methodology (Wieringa 2014).

With this motivation, this workshop has the objective of discussing best practices when conducing engineering education and research in collaboration with industry. At the end of the workshop, participants are expected to:

- LO1. Reflect on their work approach in collaboration with the industry.
- LO2. Share concrete actions and examples from their own experience.
- LO3. Learn from concrete actions and examples from the presenters' and the other participants' experience.
- LO4. Contribute to all participants' common understanding of opportunities and challenges of Industry as Laboratory (IaL), Challenge-Based Learning (CBL) and the use of the Spiral Approach for Systems Engineering Research (SASER) when conducing engineering education and research in collaboration with industry.

This workshop's relevance to the Engineering Education community lies on assisting to devise techniques to resolve industry-academia tensions related to supervision of research and education. By using a spiral approach like SASER, either independently or in combination with CBL, a closer fit between academia and the industry needs can be achieved.

2 BACKGROUND AND RATIONALE

Industry as Laboratory (IaL), and Challenge-Based Learning (CBL) are prime examples where academia meets the industry both in terms of research and education. IaL is a research approach that improves relevance for industry by embedding parts of the research in real industry settings (Potts 1993). CBL brings industry challenges to the classroom and to research (Christersson et al. 2022). However, both IaL and CBL face the challenge of aligning traditional academic work with fast-paced industrial processes (e.g., extensive and time consuming analysis, may lead to lost interest by the company). SASER was created by recognizing that (1) industry partners in research or education endeavors are not comfortable with long investigation cycles, and (2) young researchers struggle to turn actionable a set of somehow linear research questions or research objectives. This often reduces the industry interest, creates tension between academia and industry, and weakens the will for collaboration.

SASER is an empirical approach that addresses the aforementioned problems (Bonnema, Pereira Pessoa, and Nizamis 2022). SASER explicitly embraces the reality where research questions are not self-contained and that the work is rather cyclical and not linear. During each spiral intermediate results are created, which deliver value to the industry partners and bring good feedback to the researcher.

This is particularly relevant in the case of design research, where research methodologies like the Design Research Methodology - DRM (Blessing and Chakrabarti 2009) and the Design Science Methodology (Wieringa 2014) depict the research activities in a linear fashion and, although mention feedback loops, do not give further insight on how to deal with them. Furthermore, feedback loops are often considered negative and are related to fixing issues found during the sequence of actions. In the engineering practice, though, modern design processes embrace the positive aspect of feedback loops and sometimes even define the design activities to benefit from it. This is the case of the spiral model, which was first described by (Boehm 1988) in the case of risk-driven software development.

In this context, when comparing SASER to the Design Research Methodology, the idea is that research questions could be partially answered through a set of planned spirals. Specific deliverables are produced at the end of each spiral for receiving feedback, where feedback could be received from the industry partner and or from external specialists, which the case of peer-reviewed journals and conferences. Figure 1 illustrates SASER in comparison to the CBL steps and to the DRM phases, where the main research questions are divided into sub questions, which are answered during each spiral. Intermediate deliverables produced at the end of each spiral allow receiving feedback, which is important to reduce the risk to sufficiently and satisfactorily answering the overall research questions.

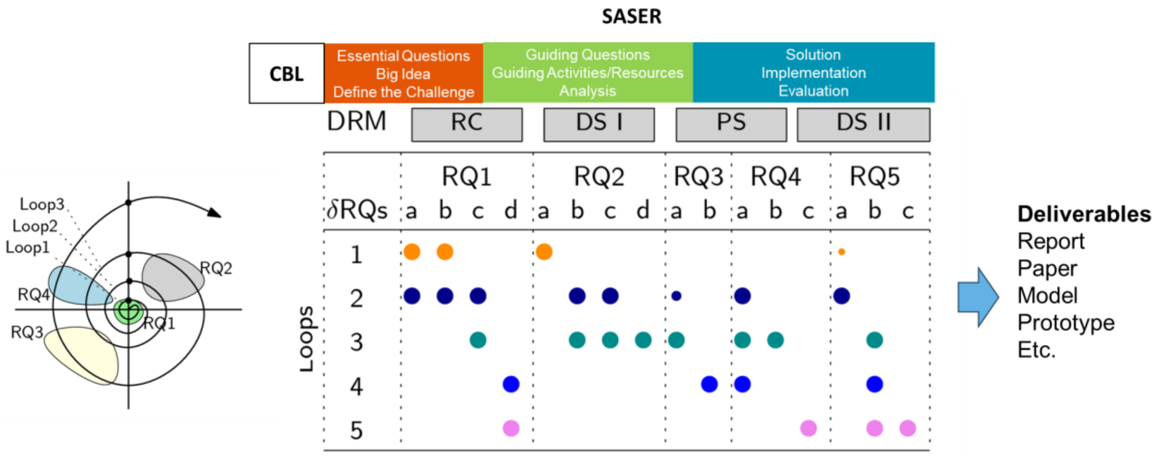

Figure 1. Decomposing the research questions to use the spirals.

To use SASER, there are some pre-requirements to the framed research or challenge. First, there is the need to have a client, which is the industry partner or any other organization or person with vested interest on the research results. Second, the research requires the design of the result, either tangible or intangible. Third, the result to be designed must benefit from decomposition and approaching it in parts. Finally, SASER is not limited to systems engineering but can be applied during any engineering research or project.

3 WORKSHOP DESIGN

This section describes the planned workshop activities and the cases used during the workshop. No previous knowledge was required to attend the workshop, and its target audience includes educators that have interest in working in collaboration with industry, either during education or research.

3.1 Workshop activities

To achieve the planned learning outcomes, the workshop activities will follow a cycle of learn=>apply=>reflect (table 1).

Table 1. Planned workshop activities.

Activities	Activity duration	Learning Outcomes
Learn: The motivation and justification behind SASER is briefly presented, the workshop structure is explained, and the approach is described through an example.	10-15 min	LO1
Apply: The workshop attendees are divided into groups and receive a hands-on task, where they work in a case to define possible strategies to execute a class project or research in collaboration with industry. Although SASER is one alternative, the attendees are also expected to discuss other possibilities. Although sample cases are provided by the workshop organization, the attendees can make use of cases from their own experience. Regardless the choice, the case must include the needs from the industrial partner and the proposed research questions or learning objectives. Depending on the number of attendees, the plan is to have at least three groups, each working on a different case at the under-graduate, post-graduate, or research levels.	30 min	LO2 LO3 LO4
Reflect: The groups will share their experience from comparing SASER with other strategies for collaborating with the industry and highlight their observed strengths and weaknesses. The results of this reflection will be organized and made available to the attendees.	15-20 min	LO4

3.2 Cases used in the workshop

Two cases were offered to the attendees. Purposefully the cases gave the participants the choice between research on creating a product and research on developing a process.

Case 1 aimed at the development of a lean method for planning the lean product development of engineering products. The clients were two manufacturing companies, one from the aerospace and on from the home appliances industry. This research, therefore, is on the area of engineering product development. Its objective is to investigate, develop, and validate a lean product design and development (LPDD) planning method, where lean development encompasses value creation and waste reduction.

Case 1's overarching research question was: How to plan the design and development of an engineering product so that the lean principles of value creation and waste reduction are guaranteed during the project execution? Based on the main research question and objective, a set of secondary research questions was defined.

Investigation questions – these questions help to align concepts and identify best practices and gaps.

Q1. How are the concepts of value and waste understood in engineering and in project management?
Q2. Which are the defining characteristics from a product development process?
Q3. What is the state of the art in lean thinking applied to product development?
Q4. Which is the state of the art in engineering project planning?

Development questions – these questions breakdown the method creation into major inner processes.

Q5. How value and waste can be understood in the PDD context?
Q6. How can all the value and only the value expected from a PDD be captured in the project scope?
Q7. How can the product architecture be defined so that it embeds all the identified value and reduce the risk of waste?
Q8. How to define a schedule that guaranteed the value creation and the waste reduction?
Q9. How to answer questions 6, 7 and using a minimum set of existing tools or techniques?

Validation questions – these questions aim to validate the developed method through different perspectives against the best practices, and to analyze to what extend it fill the identified gaps, it produces useful results, and it is practical to use.

Q10. To what extend does the method sticks to the identified best practices?
Q11. To what extend does the method fills the identified gaps?
Q12. To what extend does the method produce useful results?
Q13. To what extend is the method practical to use?

Case 2 aimed to investigate the option of developing robotic exoskeletons for the upper extremity to allow people with Duchenne Muscular Dystrophy (DMD) interact with their immediate environment. DMD is a congenital neuromuscular progressive disease affecting mainly males. Modern pharmaceutics prolonged the lifespan of people with DMD, however, the progressive nature of the disease results in lower quality of life and independence. This research, therefore, is on the area of designing a biomedical product for a specific population. Its objective is to investigate, develop, and validate a hand exoskeleton for people with DMD.

Case 2's main goal is "the characterization of the neuro-motor function of the hand, the decoding of hand motor intention decoding and the implementation of this in an active hand support for individuals with DMD." Based on this goal, a set of research questions was defined:

Characterization questions – these questions help to align concepts and identify best practices and gaps.

Q1. What is the state-of-the-art on medical devices that support the hand function of people with DMD?
Q2. What is the state-of-the-art in the development of hand exoskeletons in general?

Q3. What is the hand cognitive-motor performance of people with DMD compared to same age healthy people?
Q4. What is the available range of motion of the fingers of people with DMD?
Q5. How can we effectively interface a robotic exoskeleton with people?
Q6. Which of the ways to interface with people, are still feasible for people with DMD?

Development questions – these questions breakdown the method creation into major inner processes.

Q7. How can we effectively decode hand motor intention from people with DMD from the available interfaces?
Q8. How can we translate this motor intention into commands for a robotics exoskeleton?
Q9. Are the identified ways of translating motor intention into robotic commands feasible for people with DMD?
Q10. Which robotic exoskeleton design fits the specific situation of our target population?
Q11. How can we interface with the robotic exoskeleton?

Integration and Validation questions – these questions aim to validate the developed method through different perspectives against the best practices, and to analyze to what extend it fill the identified gaps, it produces useful results, and it is practical to use.

Q12. How can we integrate the previously generated knowledge into a complete system?
Q13. To what extend does the system work and perform the functions expected?
Q14. To what extend does the system deliver value to the patients in practice?

4 WORKSHOP EXECUTION AND GATHERED FEEDBACK

8 participants attended the workshop and were split into 2 groups of 4 people (the 2nd group decided to split further into a group of 3 and one individual). All groups selected case 2 for applying SASER. As a result, three research development plans were made. All 3 groups followed a very similar logic in performing the exercise and applying SASER, however, there were differences mostly attributed to the way each group perceived the problem, the research questions and their hierarchical placement within the overall research context. Although the number of spirals differed slightly, all of them centered each spiral in one or two development questions, where the characterization questions and the selected integration questions were directly related to the development questions (Figure 2).

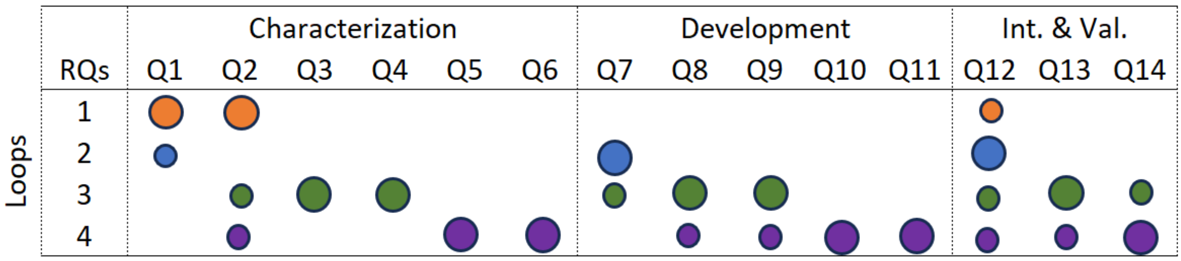

Figure 2. Example of SASER-based plan for case 2.

After they were done with arranging the research questions in loops using the SASER template (Figure 1), we used the last 10-15 minutes to reflect and discuss their choices and we made an integrated SASER picture with all their approaches drawn with different colored markers. Following the discussion, the participants filled post-its offering constructive feedback, remarks and considerations on the workshop, but more importantly on the application of SASER for organizing research in a spiral way (Figure 3).

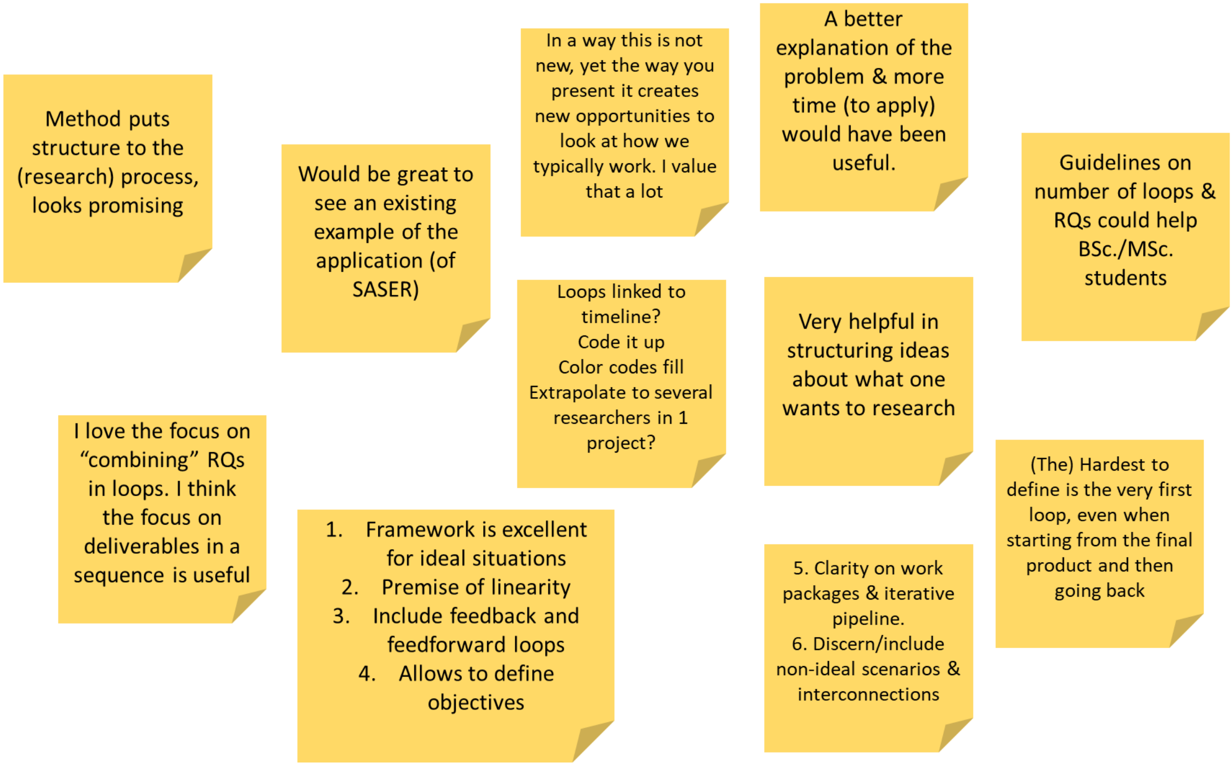

Figure 3. Received feedback.

5 CONCLUSIONS AND SIGNIFICANCE FOR ENGINEERING EDUCATION

The SASER approach targets academics, practitioners of education, and people working in the education or research collaboration between industry and academia. In the context of engineering research, the expected benefit is enhancing the educators' competence on supervising research and on defining a research methodology in the case of industry-based research. In the context of engineering education, the expected benefit is enhancing the educators' competence on creating a challenge solving dynamic, which enhances the mutual gains from the interaction between academia and industry. By increasing such competences, the educators can augment the supervised students' confidence, avoid being trapped into the analysis phase, guarantee that the work delivers value to industry, and strengthen the relationship with the industry partners.

The feedback received during the workshop (Figure 3) pointed that he main contribution from SASER are that it: (1) provides a structure and a process for organizing research with the industry involved; (2) has a clear, explicit focus on deliverables; and (3) offers clear feedback moments.

However, the comments also raise a few interesting points for improvement. So far we only applied SASER in Ph.D. projects within the SEMD research group at the University of Twente. So, indeed there is a need for adaptation of SASER to serve the research needs and circumstances of BSc. and MSc. assignments. The authors are currently researching the feasibility of SASER with master students. These cases are planned to be compiled as a library of examples of SASER applications, which is also in line with the feedback received by the workshop attendees. The authors also observed the difficulty of defining the very first loop, which could also be solved by having more examples.

What was however missing in this workshop (for practical reasons) was the presence of multiple stakeholders (academic and industrial). SASER is an output of constant communication between the different involved parties, in an effort to define a balanced and widely interesting research plan.

Lastly, there was the suggestion to make a software tool out of this process, so that multiple researchers are connected to the same SASER, and a timeline is provided. However, as we are still exploring the feasibility and usefulness of SASER we prefer revisiting this suggestion in the longer term.

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