REFINING ENGINEERING MSc THESES WITH A FOCUS ENHANCING STRUCTURE MODEL

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ABSTRACT

We discuss a conceptual thesis structure model and visual tool for enhancing the writing process in the context of an engineering Master's thesis. Our model is based on visualizing the thesis as a series of funnels that adjust the writing focus to the desired scope in each individual chapter. At the end of the thesis, the focus is widened back into the original topic area with a reflection on how the solutions proposed in the thesis have impacted or potentially will impact the field. Using our model gives students the opportunity to write a good master's thesis in various engineering disciplines. In our experience, the Focus Funnel approach has been very useful and effective, resulting in an overall improvement in the quality of engineering Master's theses in our degree program.

KEYWORDS

Engineering education, Master's thesis, Final Project, Learning tools, Standards: 2, 5, 7, 8, 11.

INTRODUCTION

For students studying towards a Master's degree in engineering disciplines, the Master's thesis and the related engineering project in the final year of studies are a demanding and challenging effort. For some, the thesis may be the first extensive independent academic writing task they have encountered, far more demanding than the Bachelor's thesis of their previous degree. To complete the Master's thesis, the students need to apply their technological skills, abilities and learnedness into identifying an engineering problem, studying its relevance to the field, proposing and designing a solution to the problem, testing and analyzing the solution and evaluating its merit. The thesis is very often commissioned by a company, meaning that an efficient and capable thesis student may get directly employed by the thesis commissioning company, potentially leading to a successful career in the industry. On the other hand, a scholarly oriented student would seek a thesis topic in a research group, striving for a salaried PhD candidate position upon completion of an academically excellent Master's thesis.

For any Master's thesis to be completed, a carefully crafted thesis plan is needed. It is a long way from a potentially interesting topic area to identifying a relevant problem, let alone to compose a solid thesis plan aiming to study the topic and to solve the problem in a way that will positively contribute to the discipline and the field. In the planning, a vital part of the process is for the supervisor to provide the student both with a wide view of the problem area and simultaneously a sufficiently narrow focus within which the thesis topic is defined. The process

takes many iterations from the initial idea to a real-world implementable plan requiring significant time and effort from both the student and the supervisor. Therefore, all tools and methods that expedite the process and make it more systematic are of extremely high value.

In this paper, we present our structure model and visual tool for systematic thesis planning and supervision called the *Focus Funnel*. Focus as an abstract concept can be difficult for students to understand in sufficient depth, and as a result, many theses exhibit issues with defining the scope and width of the topic area and the lack of focus on a specific problem or field. The main concept in the Focus Funnel is to efficiently bring the topic area of the thesis into focus while at the same time improving the readability, coherence and overall impact of a thesis. Within the focus, content is narrowed down to the specific problem at hand and its applicable area, problem statement, design and implementation of the proposed solution, and analysis of results. At the end of the thesis, the focus is widened back into the original topic area with a reflection on how the solutions proposed in the thesis have impacted or potentially will impact the field.

While research literature on academic writing is plentiful, relevant previous work on the design of an academic engineering thesis regarding writing focus and structural models is sparse. Research focusing on assessment (see c.f. (Kim, 2010; Valderrama et al., 2009; Vijayalakshmi, Desai, & Joshi, 2012)) and writing practices in engineering (see c.f. (Berdanier & Zerbe, 2018; Braine, 1989; Goldsmith, Willey, & Boud, 2019) can be found, but research and discussion on formal structural models and conceptual tools for engineering theses are yet lacking in the literature. The goal of this paper is to provide a starting point for further discussion.

In our experience, the Focus Funnel has been a very useful and effective tool the use of which has resulted in an overall improvement in the quality of engineering Master's theses in our degree program.

The rest of the paper is organized as follows. Section 2 describes the engineering degree structure within which our model is applied. Section 3 discusses the thesis planning process and goals. Section 4 presents the Focus Funnel model and Section 5 discusses its application in thesis design. Section 6 briefly discusses the role of an overall thesis plan, and the paper ends with a discussion in Section 7.

ENGINEERING DEGREES AT UNIVERSITY OF TURKU

The universities in Finland adhere to the agreements between European countries to ensure comparability in the standards and quality of higher education qualifications, also known as the Bologna process. The study credits are measured in European Credit Transfer and Accumulation System (ECTS) study points, where 1 ECTS credit corresponds to 27 hours of work, and the workload of one academic year is 60 ECTS credit points. The Finnish implementation in scientific universities (like our university, the University of Turku) is a 180 ECTS Bachelor's degree (3 years) in the first cycle of higher education and a 120 ECTS Master's degree (2 years) in the second cycle. Finnish universities of applied science have a different implementation in terms of ECTS credits per cycle for degrees. In the engineering sciences, the second cycle degree awarded by scientific universities is Master of Science in Technology, M.Sc.(Tech.). At the University of Turku, the M.Sc.(Tech.) degree consists of compulsory study modules in the major subject, a compulsory minor subject, elective studies and the Master of Science in Technology thesis. Figure 1 presents the degree structure in detail including the ECTS credit points required for each study module.

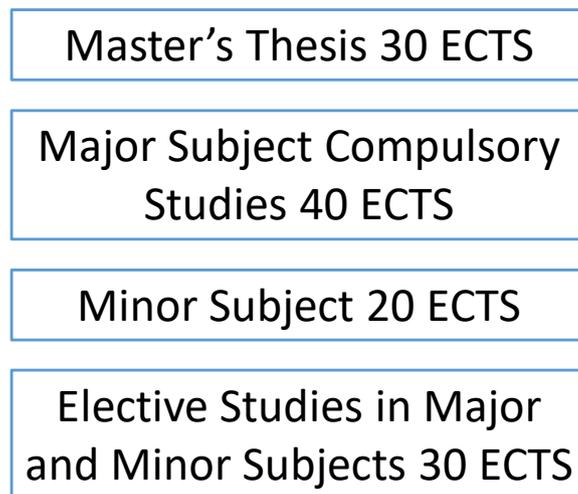| Master's Thesis 30 ECTS |
| --- |
| Major Subject Compulsory Studies 40 ECTS |
| Minor Subject 20 ECTS |
| Elective Studies in Major and Minor Subjects 30 ECTS |

Figure 1. Structure of the Master of Science in Technology degree at
the University of Turku.

The minor subject is individually selected to each student to build a special expertise profile according to the student's desired specialization; for example, in our Master's Degree Programme in Information Security and Cryptography, the major subject would be *Security of Networked Systems*, and the minor subject could, for example, be *Information Technology Management* for students considering a career path towards the duties of a Chief Information Officer (CIO) or similar.

During the final year of the studies, the students complete the Master's thesis, yielding 30 ECTS credit points and corresponding to six months of full-time work in the ECTS system. At the University of Turku, the Master of Science in Technology thesis the student must show the ability to do scientific work, management of research methods, knowledge of the research field, and the skills in scientific writing. The goal is to train the student to do theoretical (based on scientific literature) and practical analyses of research problems, conceive and propose solutions to them, design and test the solutions or a subset of them and to report the results in written form. The thesis process increases the student's knowledge and learnedness in the topic at hand, building in part the student's own special expertise profile. A well-made thesis may also lay a basis for continuing studies towards a doctorate. All completed theses at the University of Turku are public documents and the material contained in the published thesis cannot be controlled by a non-disclosure agreement.

THESIS PROCESS AND INITIAL PLANNING

The process of starting a master's thesis varies between universities. In some, there may be an application process and a formal permission is required for starting a thesis. In others, the process may be quite informal. At the University of Turku for theses in the engineering disciplines, the process is closer to the latter. When a student is ready to start writing a thesis, the first contact is with a designated faculty member who has an initial discussion with the student on their plans. Some students have a ready topic and plan, often from the company, the student works at, while others may have no topic at all in their mind.

In an engineering thesis, the goal, in general, is to provide a solution to an engineering problem through a systematic process of design, testing, analysis and improvement. The emphasis of an engineering thesis is on the practical part, and therefore it is beneficial to the student to quickly get to the "meat" of the issue at hand. When writing the thesis, the student needs to proceed from theoretical frameworks to practical questions relatively quickly, but without sacrificing scientific robustness and wider context to the theoretical background. At the end of the thesis, when the engineering problem has been solved, it is also important to contextualize practical observations made in previous chapters back to relevant theoretical frameworks presented earlier in the thesis.

Because the solution-oriented approach described above is often taken when writing a thesis in engineering fields, we have found that a common structural template is suitable for a significant part of theses. We will discuss the structural thesis template that we use in our lab later in this paper, but first, it is necessary to introduce the conceptual model that is used in conjunction with the structural thesis template.

FOCUS FUNNEL MODEL

The Focus Funnel conceptual thesis model is based on a visual funnel-like approach to bringing the topic area into focus and improving the readability, coherence and impact of a thesis. By following and checking their work against this model, the student can more easily maintain the writing focus and improve the quality, readability and impact of their thesis.

The Focus Funnel model is shown in Figure 2. This is how the model is presented to prospective thesis workers when discussing thesis structure and how to approach writing a thesis in our lab. Starting from the wider topic area description and background information in
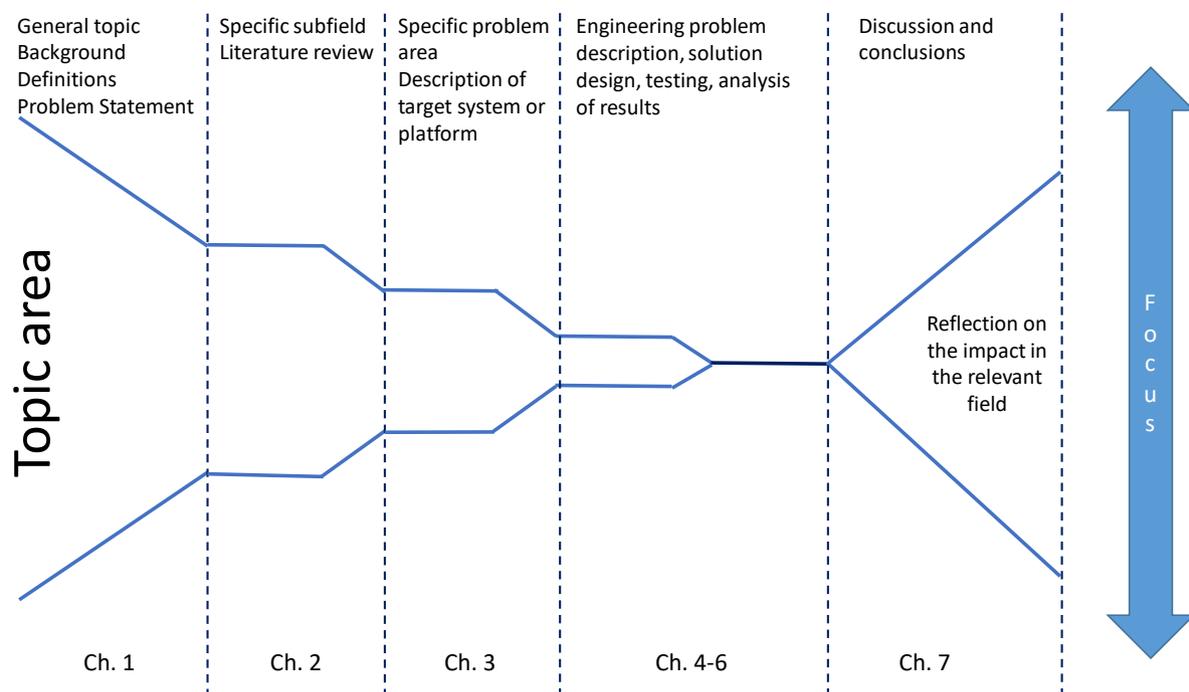

Figure 2. Thesis Focus Funnel model.

the first chapter, the Focus Funnel instructs the writer to narrow the focus of the thesis quickly into the specific sub-field of the thesis in the next chapter. Subsequent chapters should further narrow the focus down to the specific problem at hand, its applicable area, and finally to the engineering problem statement that is at the core of an engineering thesis. Next, design and implementation of a solution to the presented engineering problem follow. The results of testing the implementation are analyzed next, giving insight into how well the proposed solution solves the original core problem according to the metrics chosen for the measurement. Finally, at the end of the thesis, the focus should be widened back into the original topic area with a reflection on how the solutions proposed in the thesis have impacted the field. For many students, getting to this phase can already be laborious, but this last and perhaps most important part of the thesis is often overlooked. Often a student reiterates their results from the previous chapter and concludes that the core engineering problem of the thesis has been solved (or not, followed by analysis on *why* not) in the reference frame in which the research question is posed.

What is often missing, and what our Focus Funnel model emphasizes upon, is wider reflection on the general relevance of the results to the field. Granted, more academically inclined students will gravitate towards this approach, perhaps reflecting a better grasp at the "big picture" – something that is a necessity when aiming for PhD studies. This part is often overlooked by students and inexperienced supervisors, and it is thus important to stress the importance of widening the focus of the thesis in the discussion phase, up to creating a model such as this and systematically driving all students to consider this when writing their thesis.

APPLICATION IN DESIGN OF THESIS

To facilitate the structural design of the thesis based on the Focus Funnel, we have developed a common structural template based on the funnel. The structural template is suitable for a significant part of the engineering MSc theses, and together with the Focus Funnel, it forms the basis for creating the initial thesis plan. The structural template is a description of the typical chapter-wise content of a proper thesis. The following presents the chapter-wise guidelines provided to students after they are introduced to the Focus Funnel. The chapter numbers are not fixed in the process; the structural plan includes Chapter numbers as a point of reference only. For example, what is listed as Chapters 2-3 below might be three chapters in one thesis and just one in another thesis, depending on the exact topic of the thesis.

Chapter 1 of the thesis is the Introduction. It should present a general introduction to the topic area, leading up to identifying some problem(s), shortcoming(s) and/or R&D need(s) that are relevant and will be discussed in the thesis. The last two paragraphs of the introduction are extremely important in terms of identification of the problem, motivation of the overall content, and mapping the content together to form a whole:

- **"In this thesis a new ... is proposed ..."**: This is where the student identifies the main thing done in the thesis, why it is important and relevant (and to whom), how should it be solved, what parts of it are solved in this thesis and what is left for future work, how will the field be affected by the thesis. We ask the student to consider in which way the world will be a better place after this thesis is published.

- **"The rest of the thesis is organized as follows"**: The student is instructed to give an outline of the thesis, explaining how the chapters of the thesis are relevant for the problem identified in the previous paragraph and how the chapters relate to each other. When such a description of the organization of the thesis is provided here, no reader

will need to question it later when reading the thesis as the student already has explicitly stated the necessity of each chapter.

Chapters 2 and 3 of the thesis review relevant background information, literature and/or scientific theory. It should contain for example relevant findings from history, industry and the state-of-the-art. The covered theoretical background is necessary for the reader to understand the rest of the thesis and the choices made by the student in it. There can be more than one of these background chapters if necessary; for example, there could be one chapter dealing with background and literature and another one dealing with the details of some specific communication protocol that needs to be understood in order to understand the rest of the thesis.

Chapter 4 is the description of an existing target system used in the thesis as the platform or the technological basis for the design and implementation of the main contribution. It is a continuation of the background information provided to the reader in order to understand the main contribution of the thesis. The target system could, for example, be a firewall/intrusion prevention system, a microprocessor, an embedded system, a software suite, an SDK or an outdated in-house product on top of which the new contribution is built in the thesis. There can be more than one of these existing system chapters if necessary; for example, one chapter presents an in-house platform and another one presents the development environment used for the design and implementation.

Chapter 5 presents the specification and design of something new based on the information presented in earlier chapters. This could, for example, be improving a part of the target system based on a theoretical analysis and an analysis of shortcomings of the existing system, based on the needs of the company that has commissioned the thesis.

Chapter 6 presents the implementation and verification of (a part of) the newly specified and designed contribution as described in Chapter 5, including the analysis of results and a discussion of the significance and success of the implementation as well as the shortcomings of the solution. Instead of the physical implementation, this may also be a simulation and an analysis of simulation results, depending on the thesis topic.

Chapter 7 is the conclusion of the thesis. It provides concluding remarks, a discussion of the relevance and significance of the obtained results and how generalizable they are beyond this thesis. This chapter also outlines the sorts of future work that is already planned or could be done based on the work presented in this thesis. The author should revisit the original broader topic area and provide a reflection on how the solutions proposed in the thesis have impacted or will impact the field.

The Conclusion chapter is followed by a properly formatted list of referenced literature. The student may choose which style of referencing is used and it must be followed consistently throughout the thesis.

THESIS PLAN

After discussing the Focus Funnel, the thesis structural template and overall thesis planning with the student, the student is tasked to start crafting the initial thesis plan. As the plan, the student is required to provide one sheet of paper containing the following:

- A working title for the thesis.

  A 3-5 -line description of the thesis content: what is the problem to be solved, why is it relevant, how does the student plan to solve the problem and test the solution, and what are the expected outcomes once the thesis is published.

- A draft table of contents, including descriptive main chapter titles and titles for 1-2 levels of subsection headings.

In the planning, the student is encouraged to consider that the thesis length should be 50-100 pages, page 1 being the first page of the Introduction chapter. In a minimum length thesis, page 50 would be the last page of the Conclusion chapter.

After a suitable planning time, for example, 1-2 weeks, a meeting is scheduled with the student to jointly review the initial plan. From here onwards, the planning is an iterative process and the plan will evolve throughout the thesis process, for example, to reflect new information acquired during the work and the possibly received additional requirements from the company commissioning the thesis. The Focus Funnel and the structural template are in a key role from the beginning of the thesis project all the way to the publication of the completed thesis.

DISCUSSION

An important observation we have made is that the same Focus Funnel can be applied to individual chapters within a thesis, thus creating a structure of embedded Focus Funnels within the thesis. When we place the model in context with an individual chapter, we can identify similarities in how the focus area of a chapter is first defined, then the focus is further narrowed down to the target level for the chapter (literature review, introduction of more complex concepts, design of solution, etc.). By designing individual chapters with applying the Focus Funnel approach to subsections, a student can keep the narrative plot of the thesis intact and assure that the individual chapters do not veer away from the focus area of the thesis. This also assures that by expanding the focus of the chapter in the final section, the issues discussed within are also brought into a wider context, therefore improving the readability and impact of individual chapters, and the whole thesis, to the reader.

While we do not claim that the Focus Funnel is the One True Way to write an engineering master's thesis, we have observed that following the Focus Funnel model makes it easier for students to write a good thesis. It helps to visualize the thesis writing process and helps significantly with the difficult task of selecting and digesting relevant literature in the literature review phase.

The success of the thesis model can be further substantiated with further study on how the use of the model affects the thesis process. We are planning a systematic study on how the use of the Focus Funnel affects the quality of engineering theses at our department, and gathering more data from other institutions, if possible.

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BIOGRAPHICAL INFORMATION

Antti Hakkala is a University Teacher in Communication Systems at Department of Future Technologies, University of Turku, Finland. He received his doctoral degree [D.Sc.(Tech.)] in Communication Systems in 2017 from the University of Turku. He has nearly 10 years' experience in teaching engineering students on cyber security and communication systems engineering, and has supervised over 70 Bachelor's and Master's theses. His current research interests include wireless network security, cyber security in autonomous systems, and security and privacy in networked information society.

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