DOES A MASTER’S PROGRAM IN ENGINEERING REQUIRE A FINAL PROJECT?

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ABSTRACT

Within engineering education frameworks worldwide, requirements for a master’s degree are diverse and very few graduate-level engineering courses are recommended for accredited programs. To ascertain how common the requirement for a final project at the master’s level is, an ad hoc review of international master’s programs was conducted. This review included several of the highest-ranking universities internationally and selected universities in Europe. From this review, it is established that the standard practice is to require students attempting a master’s degree in engineering to complete what we term a final project course, which may or may not be research-focused, and typically corresponding to one semester of work. This paper summarizes how the considered universities integrate a final project course into their programs and distinguishes how these might differ from traditional research-focused master’s dissertations. We discuss the practical difficulties of managing such projects. We conclude by providing a rubric for self-assessment and reform that aligns with the criteria for continuous improvement in a graduate program quality framework.

KEYWORDS

Final project course, dissertation, thesis, learning outcomes, rubric, Master of Science. Standards: 2, 5, 8.

INTRODUCTION

An inherent goal of engineering education is to prepare graduates for the challenges they may face as professional engineers in the workplace. Educational programs will prepare students differently, depending on the needs, traditions and cultures in the relevant country as well as the values of the specific university. Therefore, engineering programs vary (usually within accreditation constraints) and thus the graduating students will have distinct nuances to their list of graduate outcomes.

One relevant skill is the student’s ability to complete large, challenging and complex projects, where the student is required to incorporate diverse discipline-specific skills, as well as both personal and interpersonal skills. Traditionally, this particular attribute has been trained and evaluated using a final project course (FPC) positioned in the educational program towards the end of the master's qualification.

As far as possible, the learning outcomes of the FPC in engineering should reflect the main areas of the future engineer's transversal practical skills, as emphasized by Kamp (2016) and outlined in Figure 1. These capabilities should also be inherent in the learning outcomes and in any potential rubric for engineering departments' self-assessment of the FPC.

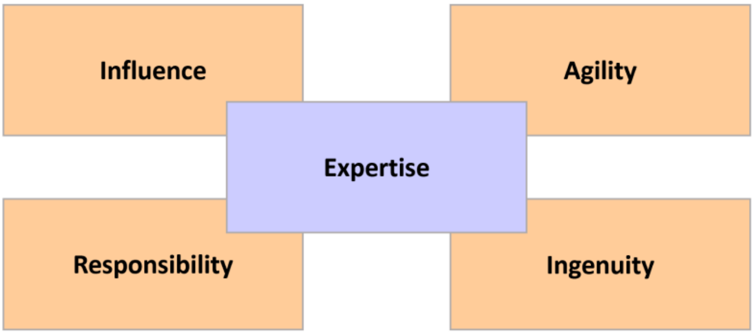

Figure 1. Five main areas of the future engineer's transversal capabilities (Adapted from Institut Mines-Telecom: *Portrait de l'ingénieur 2030* (In French, 2014), www.imt.fr/limt-presente-le-portrait-de-lingenieur-2030/).

Final project course (FPC)

In this paper we use the term final project course, as a general term to capture all the different formulations of the large, challenging and complex project a master's student may be required to complete. It is often also referred to as a final research project, final-year project, final design project, capstone project, terminal project or final internship. Typically, this FPC corresponds to one semester (approximately 30 ECTS) and is most often placed near the end of the educational program at the master's level.

We distinguish between two classes of FPC: research focused and non-research focused. The research-focused class contains the *master's dissertation*[1], traditionally found in the sciences, where the non-research focused class contains all formulations of the FPC which do not explicitly develop the engineering student's ability *as a researcher* and are typically design-focused.

The CDIO framework and the FPC

In accreditation reference and orientation guides, and in educational frameworks like the CDIO, there exist few guidelines about structural requirements of an engineering education at graduate level, and, as such, the requirements for an FPC worldwide vary significantly.

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[1] We further distinguish between a *dissertation*, which occurs at master's level and does not require an original research contribution (instead it *disserts* a specific topic), and a *thesis*, which occurs at PhD level and does have an originality requirement (by definition).

This can be contrasted with the guidelines available for undergraduate engineering education. The CDIO international framework suggests, in one of its standards (number 4), the course "Introduction to Engineering". As a good practice, it is recommended that this course is placed early in the curriculum structure thus engaging freshman students in the practice of engineering through problem solving and simple design exercises, preferably in teams. The course also includes personal and interpersonal knowledge, skills, and attitudes that are essential at the start of a course (Rouvrais et al., 2010) or program to prepare students for more advanced product, process, system, and service building experiences.

In the Design-Implement Experiences standard (number 5), opportunities to conceive, design, implement and operate products, processes, systems and services are suggested for inclusion in required co-curricular activities. For example, these opportunities should be made available in undergraduate research projects and internships at the end of the program.

Regardless of these skills being introduced and developed at undergraduate level, many leading international institutions require a further FPC at the master's level. Furthermore, there is a significant variation in the offered FPCs learning outcomes, focus and content.

In this paper we review a dozen engineering programs at international institutions and universities that culminate in a professional engineering degree at the master level, in an effort to ascertain how common a FPC is, its size (as measured in ECTS credits) and its formal intention. After summarizing the results, we discuss various aspects of the FPC, and make recommendations on its learning outcomes. Furthermore, we suggest a maturity rubric (Rouvrais and Lassudrie, 2014), as exists in the CDIO framework, to formalize the evaluation of the implementation quality of the FPC. In practice, engineering programs consider FPC a necessity and therefore the CDIO consortium may want to extend its framework to harmonize FPCs at participating universities and institutions.

SURVEY OF FPC REQUIREMENTS

At the beginning, we set out to ascertain how common a FPC is at the senior or master's level and map the similarities between the requirements where possible. The survey was conducted as an ad hoc review including some of the top-tier universities internationally and selected universities in Europe. The data was inferred from webpages of the programs, curriculum handbooks and sometimes by private communications. There are variations on how FPC is organized and therefore some details in Table 1 are institutionally dependent and prone to ambiguities. The criteria was that students graduating from the program were able to apply to become chartered engineers or professional engineers. This typically meant that the students had completed a BSc degree in engineering, or related field, and then one to two years at the MSc level.

The results are summarized in Table 1.

Based on the ad hoc survey summarized in Table 1, we may conclude that the norm at many leading international institutions and universities offering engineering degrees is that students at the master's level complete a FPC. This course can be a research or design activity, and is most often 30 ECTS but 24 and 60 ECTS variations were also observed. There is a diversity of its intended learning outcomes and style, but the vast majority of the surveyed institutions require a research-focused dissertation. Details on the FPC variations across the different surveyed institutions are provided below.

Variations in the FPC

When considering some of the top-ranking engineering institutions worldwide, MIT, Oxford and Cambridge all require a research-focused dissertation in their master's degrees. At Stanford and NTU, there are both research and non-research focused FPCs, but the non-research focused variants can only result in the award of a Master of Science (MSc) degree. Thus, all five of the top ranking institutions considered require the student to complete a research dissertation to obtain a Master of Engineering (MEng) degree or Engineer's degree (ED).

All engineering programs in Iceland require a master's dissertation, which is most often 30 ECTS in size. In the occasions where the dissertation constitutes 60 ECTS of the degree additional emphasis is placed on making an original research contribution, which is not typical at the master's level.

Throughout the rest of Scandinavia, almost all the surveyed programs require a 30 ECTS master's dissertation, with a 60 ECTS variant available at Chalmers. The exception is an option at Aalto which offers an "Aalto Thesis" FPC where "2–4 students from different fields form a team for a 6-month project to solve a work-life partner's real and complex challenge through their master's thesis", but currently this option is on a break.

In France (Rouvrais et al., 2018) the FPC is a structured internship in the industry, lasting 4 to 6 months, resulting in a final report. The student writes a report, evaluated by the company advisor, a faculty member and an external evaluator, and then there is a formal defense. This internship is the last course in the program (e.g. min 24 ECTS), other shorter internship periods exist from freshman level.

The emerging Skolkovo Institute of Science and Technology was founded in 2011 in a partnership with MIT and is based on the CDIO vision. At Skolkovo a significant part of the MSc program in engineering is devoted to a "Research and MSc thesis project" (36 ECTS out of 120 ECTS total for the MSc program, see www.skoltech.ru). The emphasis at Skolkovo is very much in alignment with the programs listed in Table 1.

Table 1a. Review of FPC requirements at top-ranking engineering institutions.

University	Structure of Engineering Program	FPC Class
University of Oxford, UK	4-year degree in Engineering Science.	
	Awards Master of Engineering (MEng).	Research focused.
University of Cambridge, UK	4-year degree in Engineering.	
	Awards Master of Engineering (MEng).	Non-research focused.
Massachusetts Institute of Technology (MIT), USA	4-year undergrad. awarding Bachelor of Science (BSc).	
	Additionally, three primary tracks of master's level study:	
	Master of Science (MS)	Research-focused.
	Master of Engineering (MEng)	Research-focused.
	Engineer's Degrees (ED)	Research-focused.
Stanford University, USA	4-year undergrad. awarding Bachelor of Science (BSc).	
	Additionally, three primary tracks of master's level study:	
	Master of Science (MS)	Non-research focused
	Engineer's Degree (ED)	Research focused.
Nanyang Technological University (NTU), Singapore	4-year undergrad. awarding Bachelor of Engineering (BEng).	
	Additionally, three primary tracks of master's level study:	
	Master of Engineering (MEng)	Research-focused.
	Master of Science (MSc)	Research and non-research variants.

Table 1b. Review of FPC requirements at engineering institutions in Scandinavia and France.

University	Structure of Engineering Program	FPC Class
University of Iceland, Iceland	5-year degree in Engineering.	
	Awards Master of Science (MSc)	Research-focused
Reykjavik University, Iceland	5-year degree in Engineering.	
	Awards Master of Science (MSc)	Research-focused
Technical University of Denmark (DTU), Denmark	3-year undergrad. awarding Bachelor of Science (BSc).	
	Additional master's program awards Master of Science (MSc)	Research-focused
Aalborg University, Denmark	3-year undergrad. awarding Bachelor of Science (BSc).	
	Additional master's program awards Master of Science (MSc)	Research-focused
Norwegian University of Science and Technology (NTNU), Norway	3-year undergrad. awarding Bachelor of Science (BSc).	
	Additional master's program awards Master of Science (MSc)	Research-focused
University of South-Eastern Norway (USN), Norway	3-year undergrad. awarding Bachelor of Science (BSc).	
	Additional master's program awards Master of Science (MSc)	Research-focused
Chalmers University of Technology, Sweden	3-year undergrad. awarding Bachelor of Science (BSc).	
	Additional master's program awards Master of Science (MSc)	Research-focused
Lund University, Sweden	3-year undergrad. awarding Bachelor of Science (BSc).	
	Additional master's program awards Master of Science (MSc)	Research-focused
Aalto University, Finland	3-year undergrad.e awarding Bachelor of Science (BSc).	
	Additional master's program awards Master of Science (MSc)	Research and non-research variants.
Institut Mines-Télécom (IMT), France	5-year degree in Engineering in 2+3 model.	
	Awards Master of Science (MSc).	Non-research focused.

SUPERVISION AND MENTORING PROCESSES FOR FPC

The role of the supervisor(s) for the FPC is to guide the student throughout the whole project and be supportive when needed, with the learning outcomes serving as the guideposts. The supervision should focus on the student's expertise and discipline, stimulate the student's ingenuity and agility, and in an effort to prepare the student for his professional life. The supervisor should, at least implicitly, make the student aware of his responsibility as an engineer and the influence he or she may have as an engineer in the future (Kamp, 2016).

Workload

The FPC is typically a significant part of the engineering program (30 to 60 ECTS), and may therefore require advising and/or supervision from faculty members. In such courses the program-level leaders of engineering departments are concerned with how to balance the workload on the faculty and external stakeholders while maintaining training and supervision quality and the autonomy of the learner.

The supervision is multi-faced and can be done either by an individual or by a small team, and the supervisor has to be aligned with the type of setting the student is working in, be it within the university or in an internship. Due to the many facets of the supervision and mentoring, the university may want to complement the advising, as for example outlined by Saalman et al. (2009). This may include pedagogical tutors, writing workshops and facilitating collaboration teams to make the students journey through this often challenging final course more fruitful (Audunsson et al., 2018) and as a discussion forum on different modes of how to approach the report writing (Hakkala and Virtanen, 2019).

To formalize and streamline the advisory process the department may set up a formal checklist with the learning outcomes and a sequence of milestones to facilitate time management. Well-prepared learning outcomes facilitate the assessment activities (Rouvrais and Chiprianov, 2012; Valderrama et al., 2009) and may aid the advisor and inform the student of the expectations during the thesis work.

Quality assurance

In addition to general quality quality assurance systems within engineering departments and institutional and external qualification framework, departments may want to consider additional requirements. The final project is a signature work by the student and reflects the quality of the educational program. Therefore one option is to mandate that the final report is open to the public and other institutions. For example, in Iceland all final reports at the MSc-level are placed in a web-based depository open to all, and the only exception is if the report contains confidential information, including market or industrial advantages. In this case, the public release of the report will be delayed for an appropriate time period. Another quality-assurance check worth considering is to have an open presentation of the project work when completed, sometimes referred to as a dissertation defense, although the term defense may not be appropriate at this level. A view from the student's side was discussed by Kindgren et al. (2012). In their paper they outlined how reflection documents submitted by students after completing a master's thesis could be used as a tool for program evaluation.

FPC LEARNING OUTCOMES

The main purpose of the FPC is to synthesize competence in discipline-specific and personal skills as benchmarked with the integrated curriculum plan. The different forms of the FPC have been highlighted, with this paper emphasizing the distinction between those that are research focused (and thus require the student to develop capacity as a researcher) and those that are not.

The learning outcomes of this final course should focus on training engineering professional activities that integrate personal, interpersonal, conceiving, designing, implementing and operating skills and competencies with disciplinary knowledge. Thus, in effect, the learning outcomes should reflect that this is the final training effort by the program to prepare the student for the workplace. The specific learning outcomes may be country specific, university or discipline specific and reflect the needs of the society in addition to the values and vision of the university. Furthermore the learning outcomes should be aligned with the CDIO framework, i.e. Standard 2, and be the culmination and synthesizing of previous courses that involve conceive, design, implement and operate.

Should Masters of Engineering be trained researchers? Not necessarily, but they should be capable of leading, managing and reporting on large, complex projects. Therefore, the learning outcomes for the final project should reflect the difference between a degree in engineering and traditional research-led master's dissertation for science degrees or future PhD students.

These objectives and learning outcomes are integrated in the rubric in Table 2, and are the cornerstone to constructive alignment with FPC activities and assessment modes (Rouvrais & Chiprianov, 2012).

REFERENCE MODEL AND RUBRIC FOR MSC FINAL PROJECT COURSE

In alignment with the CDIO principles and best practice at the master's level in engineering, we present in Table 2 a rubric for self-assessment of master's-level FPC. It includes process maturity levels to meet the coherent adoption and continuous improvement (Rouvrais & Lassudrie, 2014).

Table 2. Rubric for self-assessment for a master’s- level engineering final project course (FPC).

Maturity Scale	Criterion
5	The final project course is regularly monitored, evaluated and revised with respect to curriculum integration, learning outcomes, supervision and professional experience, based on feedback from students, instructors and other stakeholders.
4	There is documented evidence of the impact of the implementation of the final project course according to the integrated curriculum plan and constructive alignment principles.
3	FPC is being implemented across the curriculum according to the integrated curriculum plan and supervision requirements.
2	FPC has been approved by stakeholders, implemented as a research lab work, industry partnership, design or research project, with learning outcomes that train professional activities that integrate personal, interpersonal, conceiving, designing, implementing and operating skills and competencies with disciplinary knowledge.
1	A curriculum analysis has been conducted to identify the need for a FPC to synthesize competence in discipline and personal skills benchmarked with the integrated curriculum.
0	There is no evidence of a final large scale project course at the MSc level engineering program.

CONCLUSION

The review presented in this paper shows that the norm at several leading universities is that students complete a final project course (FPC) near the completion of the engineering program at the master’s level, being a substantial part of their program, typically equivalent to one semester of work or 30 ECTS, and in some cases even 60 ECTS. This is inferred from an informal ad hoc survey of a dozen universities in several countries, including five top-ranking engineering institutions.

All five of the top ranking institutions considered, see Table 1a, require the student to complete a research-focussed dissertation to obtain a Master of Engineering (MEng) degree or Engineer’s degree (ED). In most of the engineering programs in Scandinavia, Table 1b, students have to complete a research-focused dissertation to obtain a Master of Science degree. In France, full collaboration with industry is a must for the FPC. Within the CDIO educational framework, there is no obvious requirement for a final project course, but rather a group of courses that involve conceive, design, implement and operate.

The main purpose of the FPC is to synthesize competence in discipline and personal skills as benchmarked with the integrated curriculum and prepare the student for engineering professional activities. The FPC can be implemented as a research lab work, industry partnership, design or an applied research project. Because the project is the student´s signature work, the assemblage of several such projects is one of many gauges on the department's output and provides significant contribution when reviewing engineering programs.

The suggested rubric (Table 2) for quality maturity of a master level engineering FPC is based on the CDIO educational framework, the placement of the FPC in the program and stakeholders interest, and the learning outcomes. The rubric is for programme level self-assessment, including mapping the process maturity level and state of adoption, as well as for continuous improvement. The proposed FPC rubric is in line with the ubrics used for evaluating the twelve CDIO standards.

It is evident that several leading universities consider FPC a necessity and in an effort to harmonize its contribution to engineering education the CDIO consortium may want to consider recognizing the FPC and include its contribution in the CDIO framework.

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