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

Haraldur Audunsson, Ralph Rudd, Ragnar Kristjánsson, Olivier Matthieu S. Moschetta

Department of Engineering, Reykjavik University, Iceland

Siegfried Rouvrais

IMT Atlantique, Lab-STICC, UMR CNRS 6285, France

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 some practical difficulties of managing such projects. We conclude by providing a rubric for self-assessment and final project course integration 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 one such view is outlined in Figure 1. These capabilities should also be inherent in the learning outcomes and in any potential rubric for engineering programs' self-assessment of the FPC.

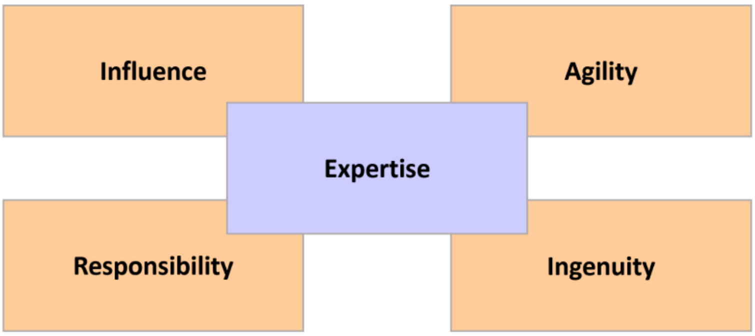

Figure 1. Five main areas of the future engineer's transversal capabilities
(Adapted from Institut Mines-Telecom: *Portrait de l'ingénieur 2030* (In French, 2014), www.imt.fr/limt-presente-le-portrait-de-lingenieur-2030/).

Final project course (FPC)

In this paper we use the term final project course (FPC), 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, whereas 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.

It is important to state up front that most programs are sufficiently vague in their FPC description such that the requirements could be met either through a research-focused or non-research focused submission. Where this is the case, our classification in Table 1 relies on the specific wording of their stated course outcomes or on the examples provided by the institution for previously completed FPCs.

[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).

For example, in the Course Learning Outcomes section from the course handbook (for 2019/2020) for the Department of Engineering Science at Oxford University (specifically as they relate to the FPC, which is referred to as 4YP in the handbook):[2]

- "The scientific practice and application of mathematics in a substantial group project (3YP) and higher-level individual project, (4YP)" on page 12, and
- "The collection, analysis and application of data through laboratory based coursework (practicals), group project (3YP) and an individual *research* project (4YP)." on page 13 (emphasis ours).

These stated outcomes led us to classify the Oxford engineering FPC as research focused. In contrast, the course website for the Cambridge Department of Engineering[3] describes the FPC as potentially involving "blue-skies research" or "direct industrial application". However, the examples they provide include: "Design of Temporary Shelters for Refugees", "Designing Long Span Bridges and Tall Buildings", "Wheelchair Design" and similar. Although these examples may include a research component, their provided descriptions led to the classification of the Cambridge engineering FPC as non-research 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.

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 or program to prepare students for more advanced product, process, system, and service building experiences.

In the CDIO 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, 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 envision to extend its framework to harmonize FPCs at participating universities and institutions.

---

[2] https://eng.ox.ac.uk/media/4738/2nd-3rd-and-4th-year-course-handbook-2019.pdf
[3] https://www.admissions.eng.cam.ac.uk/course/fourthyear

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 we used 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, four out of 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.

Table 1. Review of FPC requirements at top international institutions as well as Scandinavia and France.

	Country	University	Structure of Engineering Program	FPC Focus
Top Ranking Engineering Institutions	United Kingdom	University of Oxford	4-year degree in Engineering Science. Awards Master of Engineering (MEng).	Research.
	United Kingdom	University of Cambridge	4-year degree in Engineering. Awards Master of Engineering (MEng).	Non-research.
	United States	Massachusetts Institute of Technology (MIT)	4-year undergraduate awarding Bachelor of Science (BSc). Additionally, three primary tracks of master's level study: Master of Science (MS)[4] Master of Engineering (MEng) Engineer's Degrees (ED)	 Research. Research. Research.
	United States	Stanford University	4-year undergraduate awarding Bachelor of Science (BSc). Additionally, two primary tracks of master's level study: Master of Science (MS) Engineer's Degree (ED)[5]	 Non-research. Research.
	Singapore	Nanyang Technological University (NTU)	4-year undergraduate awarding Bachelor of Engineering (BEng). Additionally, two primary tracks of master's level study: Master of Engineering (MEng) Master of Science (MSc)	 Research. Both variants.
Scandinavia	Iceland	University of Iceland	3-year undergraduate awarding Bachelor of Science (BSc). Additional 2-year master's program awards Master of Science (MSc).	Research.
	Iceland	Reykjavik University		
	Denmark	Technical University of Denmark (DTU)		
	Denmark	Aalborg University		
	Norway	Norwegian University of Science and Technology (NTNU)		
	Norway	University of South-Eastern Norway (USN)		
	Sweden	Chalmers University of Technology		
	Sweden	Lund University		
	Finland	Aalto University	3-year undergraduate awarding Bachelor of Science (BSc). Additional master's program awards Master of Science (MSc).	Both variants.
France	France	Institut Mines-Télécom (IMT)	5-year degree in Engineering. Master's Degree of Engineering Science	Non-research.

[4] MIT is the only institution on this list to abbreviate Master of Science as "SM" instead of the typical "MS" or "MSc".
[5] At Stanford, the MS is a pre-requisite for the ED.

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.

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, and stimulate the student's ingenuity and agility. 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 (Audunsson et al., 2018) through this often challenging final course more fruitful and a discussion forum on different modes of how to approach the report writing (e.g. 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 promote 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 dissertation (FCR) work.

Quality assurance

In addition to general 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 also 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 dissertation 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 project 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.

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. The rubric includes process maturity levels to meet the coherent adoption and continuous improvement strategy (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 (FPC) 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 FPC 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 large FPC 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.

During this ad-hoc review using data available on the web it became apparent that many programs are sufficiently vague in their FPC description that it was difficult to explicitly categorize FPC as either a research-focused or non-research focused, and often both options were offered. Four out of five of the top-ranking institutions considered, see Table 1, require the student to complete a research-focused dissertation to obtain a Master of Engineering (MEng) degree or Engineer's degree (ED). In most of the engineering programs in Scandinavia, Table 1, students must 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 an integrated curriculum including 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 and 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 program-level self-assessment, including mapping the process maturity level and state of adoption, as well as for continuous improvement. The proposed FPC rubric has the same structure as the rubrics 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.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The authors received no financial support for this work.

REFERENCES

Audunsson, H., Matthiasdottir, A., and Fridgeirsson, T. V. (2020). Student´s Journey and Personal Development in an Engineering Program. *Proceedings of the 16 th International CDIO Conference*, hosted on-line by Chalmers University of Technology, Gothenburg, Sweden, 9-11 June 2020.

Hakkala, A. and Virtanen, S. (2019). Refining engineering MSc theses with a focus enhancing structure model. *Proceedings of the 15th International CDIO Conference*, Aarhus University, Aarhus, Denmark.

Kamp, A. (2016). *Engineering Education in the Rapidly Changing World*, second edition, 88 p, Delft, The Netherlands.

Kindgren, A., Nilsson, U., and Wiklund, I. (2012). Using students' reflections on program goals after master´s thesis as a tool for program evaluation, In *Proceedings of the 8th International CDIO Conference*, Queensland University of Technology, Brisbane.

Rouvrais, S., Remaud B., and Saveuze M. (2018). Work-based Learning Models in French Engineering Curricula: Insight from the French experience. *European Journal of Engineering Education* (pp. 89-102), Special Issue 45(1), online in March.

Rouvrais, S. and Chiprianov, V. (2012). Architecting the CDIO Educational Framework Pursuant to Constructive Alignment Principles. In *International Journal of Quality Assurance in Engineering and Technology Education (IJQAETE)*, Vol. 2(2). IGI Global (USA), pages 80-92, April-June.

Rouvrais, S. and Lassudrie, C. (2014). An Assessment Framework for Engineering Education Systems. In *Proceedings of the 14th intl. SPICE Conference*. 4-6 November, Vilnius University, Springer CCIS series, 447. A. Mitasiunas et al. (Eds.), pp. 250--255.

Saalman, E., Peterson, L. and Malmquist, J. (2009). Lessons learned from developing and operating a large-scale project course. In *Proceedings of the 5th International CDIO Conference*,Singapore Polytechnic, Singapore.

Valderrama, E., Rullan, M., Sanchez, F., Pons, J., Mans, C., Gine, F., Jimenez, L., and Peig, E. (2009). Guidelines for the final year project assessment in engineering. In *39th ASEE/IEEE Frontiers in Education Conference*, San Antonio, Texas, USA.

BIOGRAPHICAL INFORMATION

Haraldur Audunsson PhD is an Associate Professor of physics in the Department of Engineering at Reykjavik University. His interests include applied physics, physics and engineering education and experiential learning.

Dr. Siegfried Rouvrais is an Associate Professor of system engineering at IMT Atlantique. His current interests are in models and processes for Higher Education transformations.

Ralph Rudd PhD is an Assistant Professor of financial engineering in the Department of Engineering at Reykjavik University. His current research is focused on numerical methods in finance.

Ragnar Kristjansson PhD is an Assistant Professor in electrical engineering in the Department of Engineering at Reykjavik University and is involved in curriculum development in engineering.

Olivier Matthieu S. Moschetta PhD is an Assistant Professor in mathematics in the Department of Engineering at Reykjavik University. His interests include functional analysis and math education.

Corresponding author

Haraldur Audunsson
Reykjavik University
Department of Engineering
Menntavegur 1, 102 Reykjavik
Iceland
haraldura@ru.is