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Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

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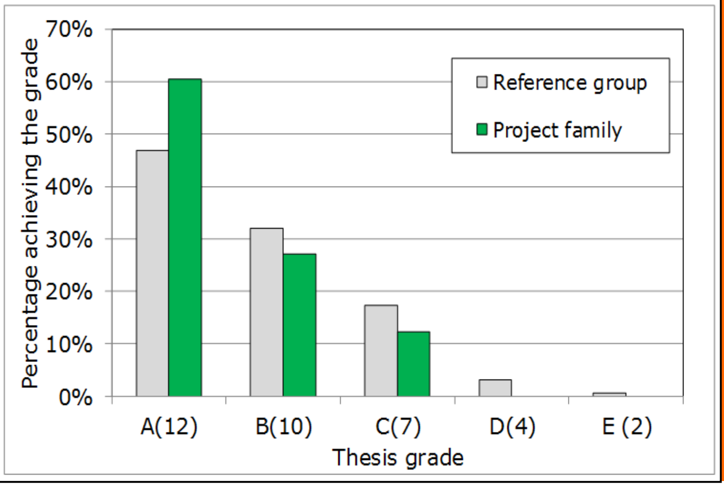

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BYG R-402, 2018

DTU Civil Engineering

Rapport BYG R-402
2018

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Cover foto: Project family. Foto: Per Goltermann
Published by: Institut for Byggeri og Anlæg, Brovej
Requested: www.dtu.dk

ISBN: 9788778774996

Project families: How to improve learning in thesis works and increase impact on research

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ABSTRACT

This paper describes the development of a new concept for organizing thesis work and supervision with the purpose of improving civil engineer students learning within the general key competences and increase their contribution to research and development, by using the student, supervisor and technicians resources in a more efficient way.

This concept organizes the traditional thesis works with 1 or 2 students collaborating at a project and a report into project families. A project family consists of a number of project students focusing on a common problem, where the students works supplement each other, share the supervisor team, test facilities, data and project room, while still being independent.

The paper presents results for 104 students thesis works and documents significant improvements in learning and in contributions to research and thus a better and more efficient use of the students resources and of the university resources.

Keywords: Learning, resources, experiments, research

1. INTRODUCTION

A university has a number of activities, where research and teaching are the two most important and dominating activities, and the university will normally be quite keen to monitor the level of both the research and the candidates. The two activities will normally compete for the same resources from the faculty and the laboratories, but can in ideal situations be combined to achieve mutual benefits.

It is therefore of great importance to try to improve the level and volume of the research, improve the learning in the key competences and at the same time use the resources in a more efficient way.

The department of Civil Engineering at the Technical University of Denmark[1] (DTU) has many activities in teaching and produces many ECTS points with app. 20 % of the points originating from thesis works and app. 80 % from courses. The ECTS points gained from the student thesis works requires in the authors' opinion more hours of supervision per ECTS points than points from courses and it is definitely more expensive in materials and laboratory support.

The theses work is probably the most important activity in the students education, as this is where they show their true competences, where they apply what they have learned and solve problems, for which they have not been taught a solution method. This is very often projects where the students contribute to research, development and innovation.

It is therefore very relevant to reconsider the traditional concept for thesis works, where 1 or 2 students work independently with an isolated problem and to see if this concept could be improved, so the students key competences could be improved, while at the same time increasing their contribution to research and development, while at the same time using less resources.

This leads to a number of research questions

- Can we identify the most important key competences for a Civil Engineer and will these competences be the same in different regions in the world and will they change over the years ?
- Is the level of the candidates competences sufficient and are there any competences, which needs to be improved ?
- Can we increase the students learning in their projects with a new concept ?
- Can we increase the students contribution to research and development, while at the same time reduce the resources spend on basic activities (students), basic supervision (supervisors) and basic laboratory support (technicians) ?

The department started to investigate the first of these questions in 2009 and has later worked with the remaining questions until today as described in the following.

[1] The Technical University of Denmark (DTU), which educates over 50 % of all Danish engineers, is responsible for 65 BEng, BSc and MSc educations and has over the past 10 years increased the student population with 100 % (1), has decided to be a laboratory based university. DTU has over this period merged with a number of other research and teaching institutions and increased both staff and income with over 150 % (2) (3). These increases in students, staff and income have resulted in an expansion and renovation of Campus facilities (4) to increase and improve laboratories and learning facilities. DTU is at the moment in a situation, where significant changes are possible and may improve both teaching and research, provided some approaches are changed.

2. THE CANDIDATES KEY COMPETENCES AND THEIR LEVEL

2.1. Identifying the key competences

Identifying the most important key competences is extremely important for a university, just as it is to determine where such competences should be learned: At the university or later at the job.

DTU Civil Engineering was in 2009 inspired by an earlier investigation carried out for MIT in 2001 among faculty, candidates and their employers (7), but was not sure whether the results would be valid for candidates and employers in Denmark. DTU Civil Engineering therefore asked DTU LearningLab (an inhouse support for teachers to improve students learning) (8) to carry out an investigation (9) of which competences would be most important for civil engineers according to our recent candidates (with 5 years of seniority) and their employers, but also to determine where these competences should be taught (at DTU or later at the job). The questions from LearningLab matched those from the MIT investigation, although two additional competences were added ("Foreign languages" as Denmark is a small country, and "Project Management" as this is often an important part of an engineer's work). The results of the investigation are shown on Figures 1, 2 and 3.

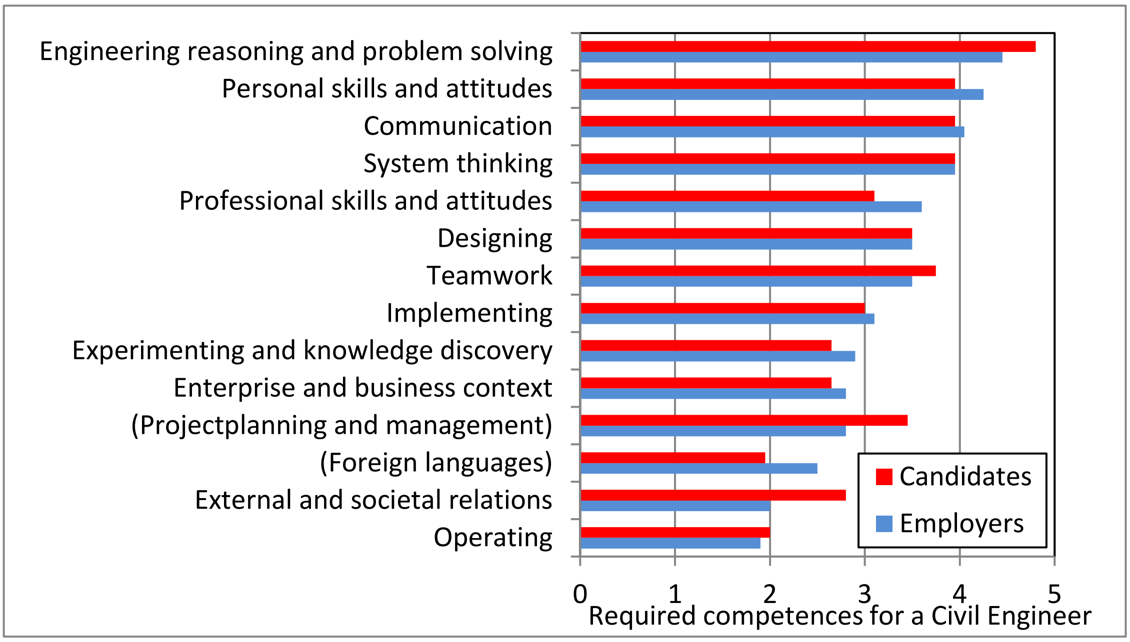

Figure 1. Importance of competences for a civil engineer (9).

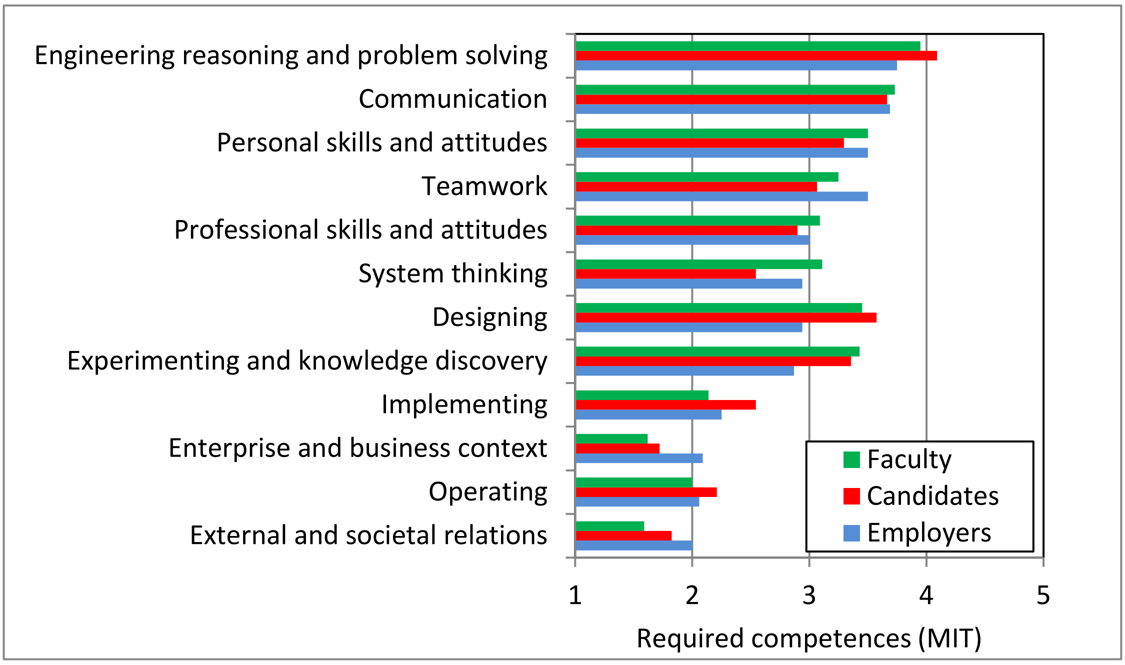

Figure 2. Importance of competences for an engineer from MIT (7).

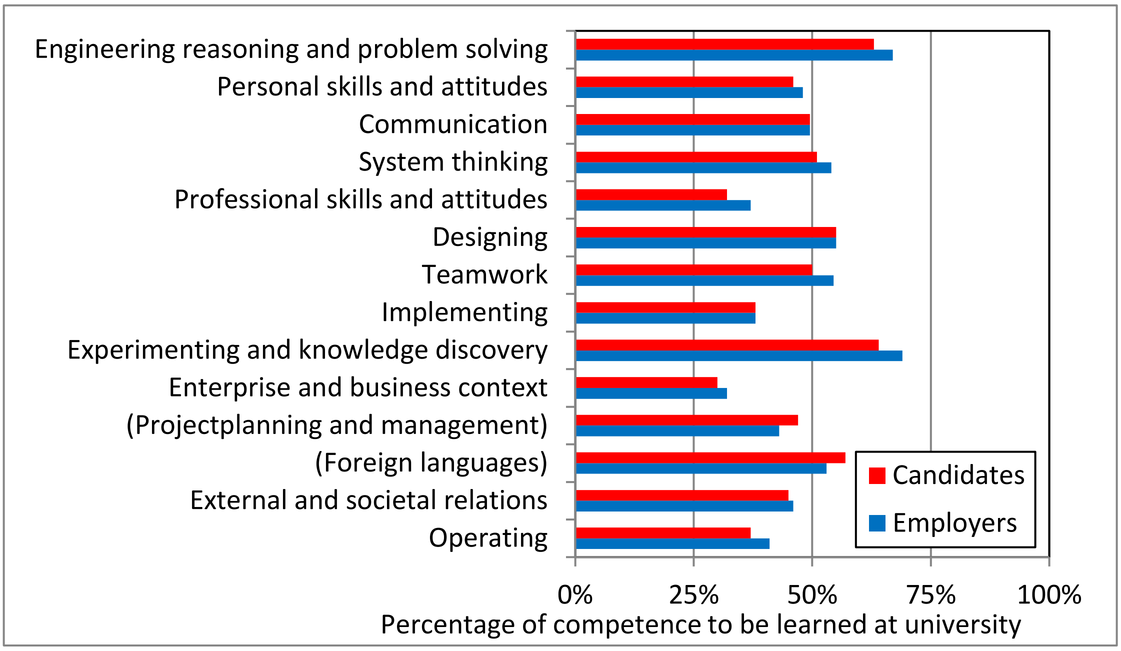

Figure 3. How large a part of these competences should be learned at the university (9).

It is interesting to see that there is a discrepancy between the ranking of the competences and those that should be learned at the university. It is seen that competences as engineering reason and problem solving, experimenting and knowledge discovery should mainly be learned at the university, whereas operating, enterprise and business context, implementing and professional skills and attitudes should mainly be learned after graduation. This investigation gives good reasons to focus most on the five listed competences at DTU and far less on implementing, operating and enterprises and business context.

The DTU investigations (9) identified the most important competences as

1. Engineering reasoning and problem solving
2. Communication (oral and written)
3. Personal skills and attitudes (initiative, thinking, critical and creative and flexible)

The MIT investigation found similar identification of the most and the least important competences (7). A number of other investigations 1988 (10), in 2006 (11), in 2011 (12) and in 2016 (13) found similar priorities of the competences, as far as the differences in the questions allow direct comparison. DTU LearningLab did not ask the faculty of their ranking of the competences, but DTU's faculty would in the authors' opinion probably have given a high importance to

4. Experimenting and knowledge discovery
5. Designing

just as the faculty at MIT did (7). According to MIT faculty, the reason for the high importance of these two competences is that they (according to the authors) are essential for the learning by providing challenges and problems for the students, for the faculty's research careers and for the faculty's ability to produce and update a research based teaching.

These investigations indicate that not only are the required key competences much the same in different locations, but they are also over time (1988-2016) found to be unchanged in importance.

2.2. Evaluating the candidates competence levels

The educations at Danish universities are all under an accreditation system, where each education is reviewed every 3 or 6 years. A part of this accreditation is a review of candidate quality. Such review is done on a regular basis through questionnaires and interviews among recent candidates and employers of our candidates (5). The reviews have confirmed that the quality of our candidates is very good and even increasing (5), (6).

The DTU Civil Engineer's Advisory Board have confirmed this, but have pointed out, that they would like to see both an improvement in all competences and an improvement in the ability to go beyond the fields the candidates already have experiences in. This ability should preferably be combined with a critical and realistic approach to potential new solutions and require a combination of the identified five key competences. The need to have an ability of combining the different key competences resulted in 2001 in the development of the CDIO concept (Conceive, Develop, Implement and operate) (7), which has been used much in the development of DTU's teaching.

The strengthening of the competences is in the authors opinion most efficiently encouraged and achieved in the students thesis work and especially in projects with either experimental activities or use of experimental results.

3. DEVELOPING THE PROJECT FAMILY CONCEPT

3.1.The project family concept

In autumn 2010 a faculty group at DTU Civil Engineering decided to reform the current concept for supervision and support for the thesis works, which at that time focused on individual projects with a supervisor (1 or 2 students may share the reporting). The reformed concept should aim at reducing resource consumption for basic supervision and basic laboratory support, while at the same time improve the students learning and their contribution to research and development by focusing a group of student projects at a common research topic, where the researchers together would form a supervisor team.

The reformed concept is referred to as project families, where students work on individual projects, but with a shared focus, supervision, test setup, project room, midterm presentation, contacts with industry etc. as described below

- Focus on the familys activities: The focus is determined each semester by the supervisor or supervisor teams and announced to the potential students, who may or may not decide to join the project family. The projects in the family may deal with different parts of a larger problem or they may deal with the same problem, but use different tools or materials. This focus and the size of the group is considered essential, as it should create a "family" feeling, where the students and supervisors together aim at solving a larger size problem, than otherwise possible.
- Supervision: The family receives supervision in a group, with additional individual supervision when needed. This motivates each student to be better prepared than usual, as he or she will be supervised together with their peers, just as it enables peer discussions.
- Experimental work: The students share instructions, test setups and their thesis budgets may be pooled to invest in materials or new equipment (supervisors decide this) or rationalise the use of the laboratory staff in basic activities. This places each student into a situation, where good laboratory behaviour is stressed by their peers, as these will be using the facilities next. It will also enable peer instructions and discussions and give the students a possibility to reach further, as they will spend less time waiting for support.
- Midterm conference: The project family usually have a midterm conference, where each project presents their results to the family, the supervisors and often a person from the industry. This mimics a phase organized approach, much used in the industry. It also provides the students with a logical midterm deadline for presenting and discussing initial findings and their future plans to peers, supervisors and the industry.
- Project room: DTU Civil Engineering will usually provide a desk for the students for the duration of their experimental work. This will be in the same room for all members of the family in order to encourage the students to share information and to enable as much peer interaction as possible.
- Cooperation between projects: The cooperation between the projects in the family is encouraged but voluntary, where the students are allowed to use the other projects results (with proper references). The grading does not evaluate this cooperation between different projects, however, a well working project group will normally help the other groups and will in return receive similar help. This cooperation is expected to support their communication skills and peer discussions can be a tool to improve the communication.

- Different educational levels: The project families may consist of a mixture of BEng, BSc and MSc projects with different basic knowledge, different learning levels and different number of ECTS points. This is expected to be a challenge for the supervisors, but it is expected to be a good training in communication and peer interaction with other persons with a different level and aim.

3.2.The project families and their supervision

The authors have over the years tried the project family concept in three independent research areas with different supervision teams:

- ZeroWaste (Supervisor team: Ottosen, Jensen, Kirkelund and Goltermann). The projects focuses is on utilising different ashes, crushed concrete, mine tailings and other waste materials as secondary raw materials in concrete and mortar and will always have extensive experimental activities for all projects.
- Glass structures (Supervisor team: Nielsen and Olesen). The projects focuses is on the use of glass as a structural component and will have design of joints, experimental work or numerical simulations for each project. Some projects may focus on one of these activities, others two or three.
- Strengthening of structures (Supervisor team: Schmidt and Goltermann). The projects focuses is on strengthening of beams with Carbon Fibre Reinforced Polymer bands or bars. The projects all include a combination of experimental work and theoretical modelling of the strengthened beam.

It is not optimal to use one fixed supervision concept for all types of project families, as there are differences in the types of activities in the different families, due to differences in topics and in maturity of the research area. The planned supervisions schemes are shown in Table 2.

Action	ZeroWaste	Glass	Strengthening
Start-up meeting	X	X	X
Weekly family meeting with all students, main supervisor and relevant co-supervisors	X	X	Only first month
Time required for weekly family meeting	½-1 hour	1 hour	1,5-2 hours
Individual meetings	If required	No	After first month
Project status at every family meeting	X	X	X
Task groups are formed during the period for dealing with different challenges.	No	X	X
Group instruction in experimental procedures	X	X	X
Group instruction in special computer programs	Not required	X	Not required
Sharing experimental facility	X	If experimenting	X
Midterm presentation (poster based) and discussion about further project activities	X	X	No
Sharing a joint room for all students	X	X	X

Table 2. Overview of supervision and sharing of facilities.

It can, however, be seen in Table 2, that project families use family meetings (all students are present at the same time), group instructions and sharing of experimental facilities and sharing a project room during the projects period for all family members. These things are expected to contribute to the peer interactions and help the students to perform better in testing, reporting and presenting.

3.3. Development process

The activities in the development, planning and supervision of the project families have been developed and adjusted over the period 2010 to 2017. The concept and its results have been published at a number of conferences and seminars, where the approach has been discussed with much interest. The discussions headed by the authors have been at international conferences first for the CDIO concept at DTU Civil Engineering (16), (17), (18) and later for the project family concept (19), (20), (21), (22), (23) just as the project family concept has been discussed at DTU teaching seminars and DTU teaching biennales. The project family concept has also been communicated to a larger audience for discussions with the alumnes and industry (24), (25), (26).

These discussions have been most useful for the development and adjustment of the concept, at latest in 2017, where the Nordic Concrete Association held the Nordic Concrete Research Symposium, where the Nordic Concrete Teachers network (established 2010, chaired by Goltermann from DTU and Fridh from Lund University (27)) had a session, dedicated to teaching (23), (28). The main topic in this session was the use of experimental activities and use of project families and it was decided to cooperate further on research and education, with more student involvement and use of experimental activities and project families. This approach was later highlighted in the closing session of the symposium, with especial emphasis on the “family” aspects.

4. THE PROJECTS FAMILIES AND THEIR RESULTS

The project families involved students from different Civil Engineering educations (BEng, BSc and MSc) as shown in Table 2.

Semester	Family	BEng	BSc	MSc	Sum
S2011	Glass		5		5
S2012	Glass		9	3	12
S2015	Glass		12	4	16
A2012	ZeroWaste	7	2		9
S2013	ZeroWaste		4		4
A2013	ZeroWaste	2		2	4
S2014	ZeroWaste	5	3		8
A2014	ZeroWaste	3	1	2	6
S2015	ZeroWaste	2	2		4
S2016	ZeroWaste	2		5	7
S2017	ZeroWaste[1]	3	1	3	7
S2017	ZeroWaste[1]		6	2	8
S2016	Strengthening	2	1	3	6
S2017	Strengthening		3	5	8
Sum		26	49	29	104

Table 2. Overview of the number of project students in the project families.

Note 1: The family area had two independent project families with different topics.

The results from the project family thesis works must be evaluated, although it is difficult or even impossible to have measurements for all five competences and the ability to go beyond what has already been learned.

The one thing that we have data for is their grades in their thesis and in their education and these will be used as a value for the level of their learning (that is what grades are supposed to represent and there is always an external opponent, a censor, for their thesis presentation, examination and grading). The general experiences from the supervisors, the laboratory staff and the students are determined through interviews and questionaires.

4.1.Students grades

It is difficult to measure the direct effect on the grouping of projects in project families on each of the five competences individually. The combined effects, however, can be documented by comparing the grades earned by the project family members with the grades of the students conducting their thesis work in stand-alone projects (reference group).

The reference group consists of the BEng (338), BSc (159) and MSc (395) Civil Engineering students, who carried out their thesis work at DTU Civil Engineering during 2012-16 and represents the same educations as in the project families. The weights of the three educations are set to their relative numbers in the project families, just as similar weights will be used in all other comparisons (Figure 5 and Tables 4,5 and 6) in this paper in order to have as representative a reference group as possible.

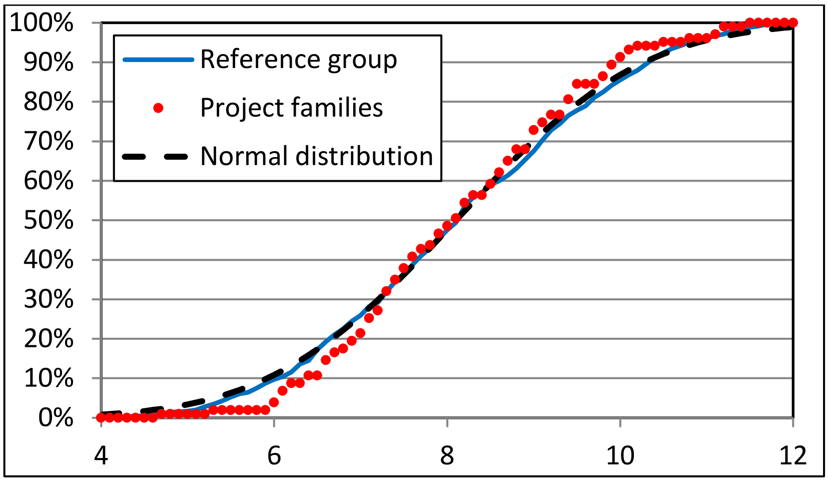

Figure 4. Accumulated distribution of average grades in the education.

Figure 4 shows the variation of the students average grades during their educations and it can be seen that the variation for the project family students corresponds quite well to the variation in the weighted reference group. The figure shows also that the grades are fairly similarly distributed as for a normal distribution and that it in the remaining comparisons would be appropriate to use the average grade from the education as a description of a groups qualifications.

The Danish grading system uses values, which but corresponds to the international grading system as described in Table 3.

DK grade	International	Description
12	A	Excellent – outstanding performance with only minor errors
10	B	Very good – above the average standard but with some errors
7	C	Good – generally sound work with a number of notable errors
4	D	Satisfactory – fair but with significant shortcomings
2	E	Sufficient – performance meets the minimum criteria
0	Fx	Fail – some more work required before credit can be awarded
-3	F	Fail – considerable further work is required

Table 3. The Danish 7 step grading scale with its values and their international translation.

The distribution of the grades for the thesis works in the project families is compared to the distribution for the reference group in Figure 5.

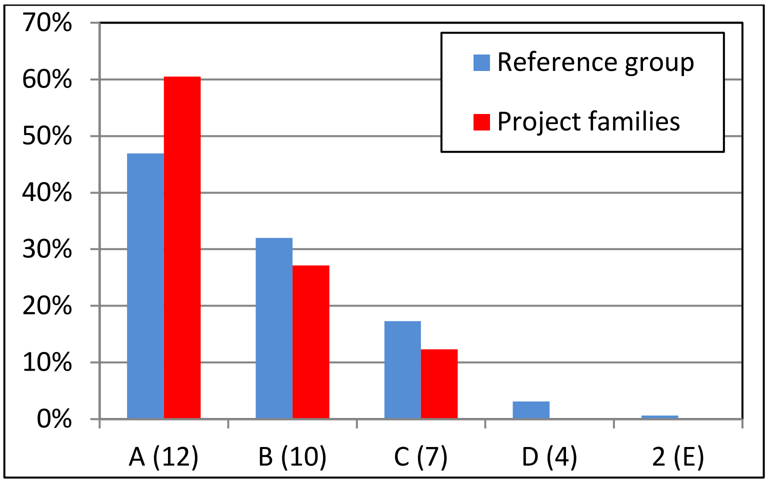

Figure 5. Distribution of thesis grades.

Figure 5 illustrates that the concept of project families leads to higher grades in the students thesis works, although the students have similar average grades in their educations in project families and in the reference group. It is, however, relevant to investigate whether this improvement is due to a special selection of students according to

- type of education or
- average grades during their studies or
- project family type (topic and supervisor team)

or if it is a real improvement, independently of these aspects.

4.1.1.Effect of type of education

Type of education	Project families			Reference group		
	Education	Thesis	No	Education	Thesis	No
BEng	7,1	10,9*	26	7,7	9,7	338
BSc	8,1	10,8*	49	8,1	10,2	159
MSc	9,0	11,1*	27	8,7	10,2	395
All	8,1	10,9*	104	8,1	10,1	892

Table 4. Average grades for students in their education and in their thesis, grouped after their education. * denotes statistical significant improvements.

It can be seen from Table 4, that the students in the project families had the same average grades from their studies as the reference group. In all three education groups, it was found that the distribution of their average grades in their education corresponded to the distribution in the reference group. The students in the project family are thus a representative sample of the full Civil Engineering student population at DTU Civil Engineering, used as reference groups.

Table 4 shows that the thesis grades are in average almost 1,0 higher in the project families than in the reference groups. This corresponds to half a grade higher in the international A-G scale and statistical analysis verifies that this is a statistical significant improvement for the full collection of students in the families (All), for the students from the BEng and BSc educations, but not quite for the MSc education. The statistical significance has been verified by a Monte Carlo simulation of the statistical variation of the average thesis grades among a similar number of students from the reference group and the 95 % confidence levels has been chosen as significant. Other levels may be used, but the 95 % level was originally suggested early in statistical testing (29) and is commonly used in the field of Civil Engineering as the normal level for significant values (30).

4.1.2.Effect of average grades in education.

Average in education	Project families			Reference group		
	Education	Thesis	No	Education	Thesis	No
Below 7	6,3	10,0*	22	6,1	8,3	227
7 to 8	7,4	10,9	28	7,5	10,0	196
8 to 9	8,5	11,1	26	8,5	10,8	178
Above 9	9,8	11,5	28	10,0	11,5	291

Table 5. Average grades for students during their educations and in their thesis, grouped according to their average grades in their educations. * denotes statistical significant improvements.

Table 5 illustrates the effects on students at different knowledge levels, represented by their average in the education. Each group in Table 5 and in the reference group represents app. 25 % of the student mass. It can be seen that the project family concept improves the thesis works statistically significant for the below average students, represented with averages below 7 (confidence level 95 %). A lesser and not statistically significant effect is observed for the two next groups around average (average 7 to 9) and no effect is observed for the best 25 % of the students. This is not unexpected as the students with the highest averages during their studies tend to receive one of the two top grades for their thesis and such grades can hardly be improved.

4.1.3.Effect of project family type

Project family	Project families			Reference group	
	Education	Thesis	No	Education	Thesis
ZeroWaste	7,8	11,0*	57	8,0	9,9
Glass	8,5	10,7	33	8,4	10,2
Strengthening	8,4	11,1	14	8,3	10,0

Table 6. Average grades for students in their educations and in their thesis, grouped after research area and supervision team. * denotes statistical significant improvements.

The Table 6 show the results as a function of the family topic and the supervision team. No major difference can be observed in the thesis grades between the families, indicating that the concept works well for all areas, despite the variations in the supervision and in the topics. It needs, however, to be said that only the ZeroWaste area has a statistical significant improvement on the thesis grades, as the increase of the thesis grades in the Glass area is less and the Strengthening area has still got too few students in the population to document a statistically significant improvement of the grades.

It is, however, also interesting to see that the improvements of the students grades are observed for all three project families, who deals with different and unrelated areas and which are (except for one supervisor), supervised by independent teams of supervisors, who also uses different external opponents for the grading of the theses.

4.2 The supervisors experiences

The supervisors were asked to give a brief statement about their most important experiences with the project families:

ZeroWaste: The weekly, shared supervisor meeting lasted for about 30 min to 1 hour, regardless of family size. A small part of the time was spent on passing general information to the students, so most time could be used on the more interesting scientific student questions and peer discussions. This approach matured the students earlier in the project period, than normally. They were able to continuously analyse their results, and plan the next steps on this basis. The work in the project families was planned so the supervisors were gradually supporting the students in taking full lead of their projects during the first month, and after the poster presentation, the students were the true project leaders, which also mean, that they need to determine the form and topics for the supervision meetings. In this part, the students had a huge benefit from hearing the questions and discussion points raised from their peers.

Glass: It is evident that the concept is scaling very well with the number of students. That said, it is important to remember that the time consumption is, to a large extend, used when planning the projects (even before the students sign up). It is also my experience that care should be taken when having students on very different level. There's no problem in having good BSc students and Good MSc students in the same family, but less motivated BSc students together with highly motivated MSc students could pose an issue. One experience in this was observed in the large family in S2015, which was automatically split into two smaller families: One consisting of the highly motivated students and another group which were not as motivated.

Strengthening: The family is a good tool for verifying- or falsifying hypothesis in the supervisors' research, investigate innovative solutions and include the students in the ongoing research together with its related practical aspects. The process was, however, still time consuming for the supervisor due to planning of the projects and supervision during the process. One of the challenging parts was the instantaneous supervision, when practical problems arise, which ensured that the students did not wait too long and at the same time produce the results needed to enable the evaluation of the hypothesizes in the project.

The supervisors found that the supervision required for basic instructions was the same for a project family as for a traditional individual project, although individual supervision was still used in addition to this. The students appeared better prepared for the project family supervisions than for the traditional projects and they spend less time on basic activities. This allowed the student projects to progress to a deeper level than traditionally and the learning and the supervision could deal with deeper and more advanced topics, as both students and supervisor had room for the more advanced experiments and discussions.

The findings from the project families have been used substantially in publications and in research activities:

- Zerowaste: A total of 8 scientific publications have been produced and additional publications are under production. Over 50 % of the student thesis has been referred to in at least one conference paper within a year.
- Glass: The projects are used as "pilot" testing in the research area. The work produced is, however, massive and 3 papers are in the pipeline using results from student theses.

- Strengthening: The projects are used to screen and test research assumptions. This project family is fairly new, but 1 publication has already been produced and 2 are being drafted.

The number of publications is expected to grow as the planned later projects are expected to complete the current works and lead to an increased number of publications. The use of the project results depends much on the type of scientific area and the maturity of the research the students participate in, but the huge amount of work the students put into their thesis work contributes significantly to the supervisors research activities.

4.3 The laboratory leaders experiences

The experimental activities were carried out in two of the departments' laboratories (for the smaller specimens in the mortar and the chemical laboratories, and for the larger specimens in the strength and concrete laboratories for the larger specimens). The leaders of the two laboratory units have been interviewed about their experiences with the project family concept and have during this answered a few, standard questions, to which the abbreviated answers are listed below.

Q1. How do you evaluate the faculty's planning ?: It is a new concept, but the planning keeps improving. It is, however, mandatory with a good planning well before the start of the projects and they need to start at the projects at the same time.

Q2. How do you evaluate the work load in the laboratory ?: It is clearly an improvement as the same test setup can be used for several projects and thus procedures needs only to be instructed once.

Q3. How do you rate the student behaviour in the laboratory ?: The behaviour has improved, they clean up, look after each other and their safety behaviour has improved. It is required to be clear about the requirements for their behaviour and performance in the laboratory.

Q4. Do you think they learn less or more ?: The students' discussions with each other improve their learning and they seems to obtain a broader knowledge. They help each other a lot in the laboratory.

Q5. How do these project families influence the work load in the laboratory ?: The amount of technicians work hours is probably reduced with 25 % in the large specimen laboratory and 75 % in the small specimen laboratory for a project family with four projects in comparison to the traditional approach with individual test setup for each project.

The laboratory leaders are much in favour of the project family approach, both because it leads to a much more rational use of the resources, but also because they observe that the students behave better in the laboratories and learn more.

4.4 The student´s experiences

A number of questionnaires were issued by the authors to the students in 2014 (11 of 14 answered) and in 2017 (15 of 23 answered), asking them about their experiences, dealing with supervision, peer-interaction, their work situation and how they rate their own performances. The responses did not differ significantly between 2014 and 2017 and are shown on Figures 6 to 9.

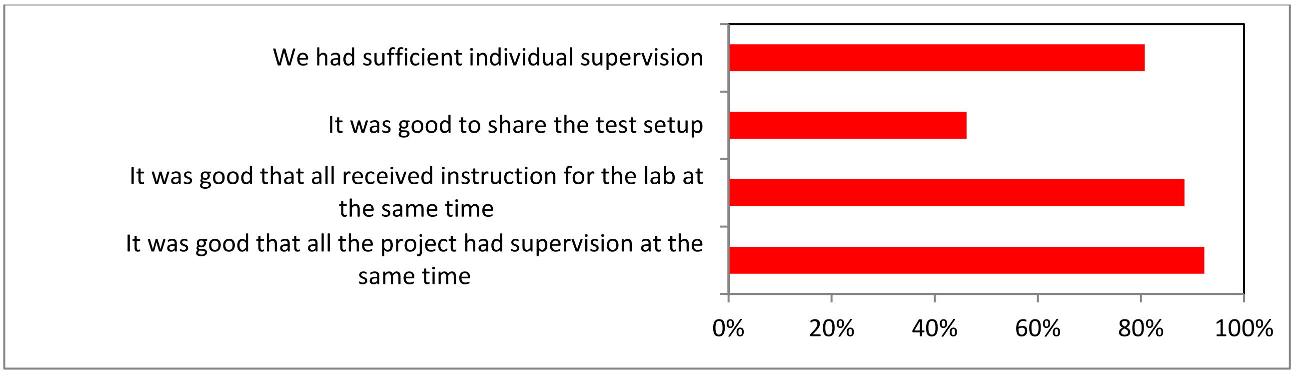

Figure 6. Question to the student: How was the supervision ? (Mark all you agree with).

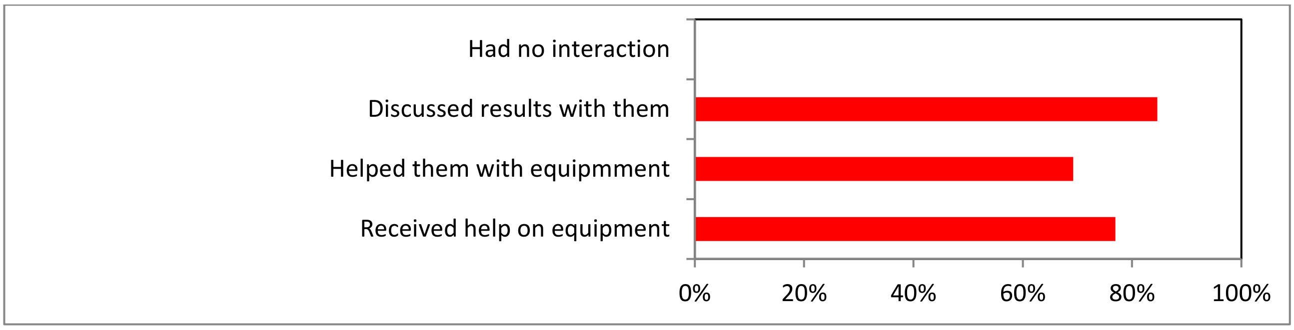

Figure 7. Question: How did you interact with the other students ? (Mark all you agree with).

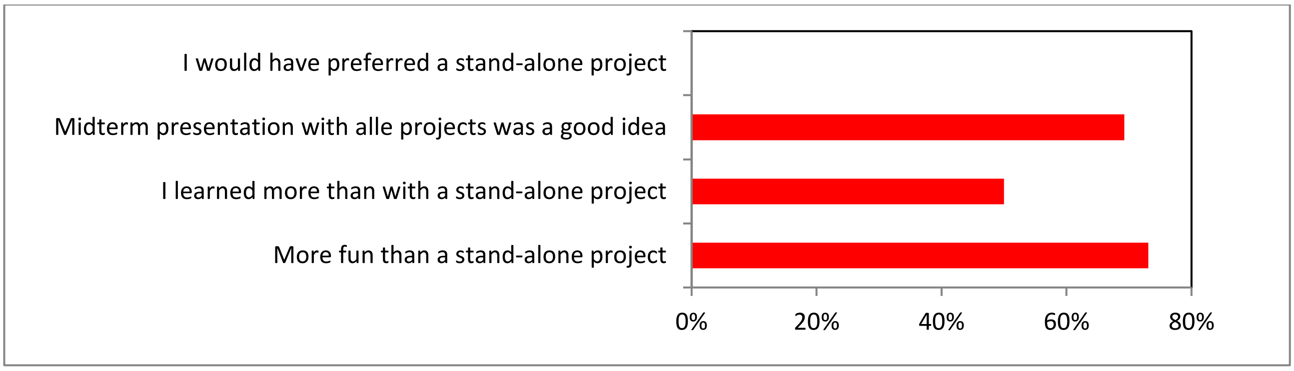

Figure 8. Question: How the students experienced the work in a project family (Mark all you agree with).

Figure 9. Question: How did the project family concept affect your achievements ? (mark only one).

It can be seen from the responses, that the students appreciated the concept of project families, they interacted and had more fun, just as they felt that they achieved more than if they had worked on an isolated project. The effects of the students average grade in their education on their evaluation of their assessments in Figure 9 is seen in Table 7.

Average in education	I achieved a lot more	I achieved more	No effect	Total
Below 7	3	1	1	5
7 to 8	2	6	0	8
8 to 9	1	5	0	7
Above 9	0	5	2	7
Total	6	17	3	26

Table 7. Response depending of the students average grades during their studies.

Table 7 shows that the appreciation of the effect of the concept is found among all levels of students, although the students with the highest average grades in their education have the highest percentage of students, who reports no effect (although most do report that they learned more). It must, as a comment to this, be pointed out that even these students have been given access to deeper supervision and improved experimental activities, often been provided and tested already by the other students.

The students did all know from the beginning, that they signed up for a project in a project family and the comments show, that the concept fulfilled their expectations. Some of the students added comments to their questionnaires or to a later interview (31), where one stated

" When you are in a project family, you have more angles to your work, You achieve more on less time, because you are constantly challenged in your way of thinking. If you work alone, that will be slower"

5. CONCLUSIONS

The work has verified, that the general competences required by a candidate from the Civil Engineering educations can be identified, that the required competences are the same in different regions over a long time period and are not expected to change (although the technologies used by the candidates changes constantly). The level of the candidates' competences is very good according to the evaluations of the candidates, but improvements will always be appreciated in the identified key competences.

The conclusion is that the use of project families improves learning, the behaviour in the laboratory and the grades, just as it increases the input to the supervisor teams research activities. The improvements on grades are largest for the below average students, whose performance can be observed to improve to match the performance of the above average students in the reference group. No effect has, however, been observed among the top level students (with grades among the best 25 %), but this may well have been caused by the fact that this group of students would normally receive an A(12) for their thesis work.

The experience is that the use of project families requires the supervisor and laboratory leaders to plan ahead of the projects, as it is essential to have the necessary allocation of staff, equipment and facilities planned in good time. The traditional, isolated projects with 1-2 students are of course easier to fit into a busy laboratory, than a project family with 8-10 students. The concept leads to a reduction of the resources spend on basic supervision and laboratory support and transfer these resources (from students, supervisors and technicians) to deeper learning and research activities and creates a better project experiences for all involved.

The experiences indicate that the size of the project family should not be less than 5, as there is too little peer-interaction and little benefit. A family size above 10 is normally not a good idea as the family in practise seems to split into several subfamilies, who work independently of each other.

The use of project families is a huge success at DTU Civil Engineering, where a growing number of supervisors (in addition to the authors) use this concept. This development will be followed closely during the next years, but it is not expected that the project families will replace the traditional, isolated projects. It is just a valuable and efficient alternative.

ACKNOWLEDGEMENTS

The authors would like to thank the laboratory leaders Ebba Schnell and Kristian Riskær for their enthusiastic help with the project families and their contributions to improve the students learning, while at the same time rationalizing the use of the facilities and resources.

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