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Towards a Conceptual Framework

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Project Types and Complex Problem-Solving Competencies: Towards a Conceptual Framework

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Abstract

Project management and collaboration are considered core competencies in engineering education, both in relation to complex problem-solving and as part of the required professional skill set. The most common way of learning both project management and collaboration skills is by introducing different types of team-based projects in the engineering curriculum and letting students reflect on their skills development. However, the student experiencing and learning during a project process depends on the team size and duration of the project work, as well as the scope and organization of the project itself, ranging from a narrower disciplinary approach to a more contextual one, incorporating interdisciplinary and inter-organizational learning outcomes.

In this paper, we present a conceptual framework for understanding the variations in educational projects and intended learning outcomes for project management and teamwork. The project typology is based on two dimensions: 1) the scientific content and problem scoping, ranging from simple and complicated problems to complex and interdisciplinary problems; and 2) the size and organization of the team(s) implicitly involving project management processes on varying levels. Combining these two dimensions results in four educational project categories: the discipline project and multi-projects, addressing single discipline learning objectives on a scale from individual discipline teams to larger team clusters; and interdisciplinary projects and megaprojects, which cover contextual, complex and interdisciplinary learning outcomes on a scale from smaller interdisciplinary teams to larger 'teams of teams', or clusters in collaborative networks. These four ideal types of project frame students' learning of various complex problem-solving competencies such as problem identification, analysis and solving, collaboration skills and project management in different ways, all relevant in engineering education. Here, we focus specifically on intended learning outcomes related to the different types of interdisciplinary projects.

Keywords: project types, complex problem-solving, interdisciplinarity, problem based learning

Type of contribution: PBL conceptual paper

1 Introduction

Complex problem-solving competency is a relatively new requirement for engineering education, becoming increasingly distinct in the accreditation criteria in the past ten years (Accreditation Board for Engineering and Technology (ABET), 2014). Here, complexity is defined as a dynamic situation characterized by interdependent variables. Therefore, establishing a system overview is a requirement to be able to identify interconnections, dependencies and boundaries, which is a complex process involving many different factors. It is an instance of knowing neither the problem nor its solution (Snowden and Boone, 2007). For complex problem-solving, there is also a demand for actors to be able to handle complexity, and since engineers are considered one of the main human resources in any technological complexity, this becomes a requirement in the engineering profession (Attri 2018). A study of problems in the workplace indicates clearly that complex and ill-structured problems are the most typical engineering problems. These problems have multiple and often conflicting goals. They, can point to many different types of solutions and success criteria and constraints are often outside the technical domain (Jonassen et al., 2006). "*Complexity of a problem manifests itself in a number of forms, including the breadth of knowledge required, the difficulty level of comprehending and applying the concepts involved, the skill and knowledge levels required to solve the problem, and the degree of nonlinearity of the relations among the variables within the problem space."* (Jonassen and Hung, 2015:page 9). The more complex and boundary-less a given situation is, the more options can be generated – and especially when dealing with real world problems, the complexity extends beyond scholastic problem-solving skills (Dörner and Funkt, 2017).

In the Problem Based Learning (PBL) model at Aalborg University, complex problem-solving is considered an integrated and essential PBL competency (Holgaard, Søndergaard, & Kolmos, 2019). However, not all PBL practices address complex problems and a more variated project-oriented curriculum is needed to include complex problem-solving. Therefore, it is important to conceptualise various project types.

The term 'PBL competencies' covers four overall categories of competency; problem-oriented, project-oriented, team-oriented and metacognitive competencies, to reflect and further develop other more domain- or discipline specific competencies. These competencies are embedded within the curriculum, and students are required to reflect continuously on them throughout their education. The four types of competency are deeply interrelated. For one thing, different types of problem call for different types of project with different team constellations. As a consequence of the increasing need for complex problem-solving, there is a need to increase diversity in the types of project that students work on. It is not enough to let engineering students focus on parts of complex systems; they also have to capture the interconnectivity and dependencies of complex systems to address wicked problems. It is not enough to work with projects from within a discipline, as complex problem-solving most often calls for interdisciplinary synergy. Therefore, diversity and variation in the project experiences is fundamental for developing PBL competencies (Fraser, Allison, Coombes, Case, & Linder, 2006; Pang, 2003).

A recent review of PBL in engineering education indicates that the most common application of projects is within existing courses rather than across courses or at curriculum level (Chen, Kolmos, & Du, 2020). In this review, the majority of the research reports single course project activities, whereas only a quarter of the papers report a more systemic approach to project activities across courses or at curriculum level. At course level, projects are mostly applied as means for students to deepen their understanding of the lectures and to enhance students' motivation for learning. The project types reported in the literature review are characterized by problems mostly given by teachers, with few possibilities for the students to identify problems themselves, with a duration of about a semester as long as the course is running, and with smaller teams of mostly three to eight students (Chen et al., 2020). Reviewing the development from 2000 to 2019, the trend is an increase in the prevalence of project activities and students' project participation increasingly becoming the norm rather than the exception in engineering programmes. However, if students experience the same types of project process throughout the educational programme, there is a risk that it becomes routine, without any deeper reflection (Kolmos, 1999) and team collaboration becomes a type of tacit knowledge or a set of non-verbal action skills, where action is not necessarily based on discussion and knowledge sharing. Although the sharing of tacit knowledge through collaboration may provide expertise otherwise difficult to obtain, non-verbal expertise might be less transferable to other situations, since the learning is created and tied to a certain situation. For the experienced expert, according to Dreyfus and tacit knowledge and intuition will be at the highest level. However, the students are in a learning situation, and it is crucial that this experience and learning is reflected and conceptualized in order for it to be reconstructed in new situations. Experiencing variation and articulating contrasts, similarities and differences is one way to encourage reflection and make tacit knowledge and collaboration explicit. Therefore, we argue that it is important that students experience variation in the type of problems and projects they participate in to break routine and to make explicit tacit knowledge and competencies. In a PBL curriculum, this variation could include:

- Problem type (ranging from simple problems to complex problems)
- Project type (ranging from narrow discipline projects to complex megaprojects)
  - Project scope varying from few credits to many credits
  - Project length varying from shorter to longer courses, from one semester to x years
- Teams and collaboration
  - Group size varying from smaller to larger groups and teams in networks
  - Group composition varying from local to international teams
  - Group formation varying from student-initiated to teacher-initiated or theory-based
  - Types of collaboration varying from specific division of labour to integrated collaboration
- Facilitation
  - Relationship between lectures and projects
  - Supervision and collaboration forms
  - External collaborators varying from external project cases to project partners
- Variation in physical and digital facilities and learning spaces

Reflection on variation is an important source for learning how to carry out problem analysis and problem definition in a professional way, and not least for learning process skills to be able to enter into and handle problem-based project collaboration—in other words, PBL competencies. Through reflection on variation, the learner becomes aware of the characteristics of the experience and its relation to other educational experiences. For instance, if a student has experience with project management only in a single discipline group, that is the experience and knowledge this student carries, whereas having experience with two or three different types of group collaboration will most likely increase the ability to be flexible and adaptable to new situations (Pang, 2003). Although there are many ways to create variation in a curriculum, in this paper we focus specifically on the structural components of projects by focusing on problems and teams.

2 Types of Projects: The Problem and Team Dimensions

A project is defined as a unique endeavour with a specific goal to solve problems, which can be divided into sub-tasks. Projects range from small teams to hundreds of people depending on the issues to be solved and the defined tasks (Algreen-Ussing & Fruensgaard, 2006). However, in many engineering curricula, students are not offered the opportunity to reflect on variation, since the types of project students are working on are similar in terms of both scientific approach and team size, two important dimensions for scaling up and expanding projects. Scaling up the scientific approach concerns expanding the range of project types from single disciplines to interdisciplinary projects, in principle determining choice of discipline and method to match a similar range from narrow discipline problems to complex problems.

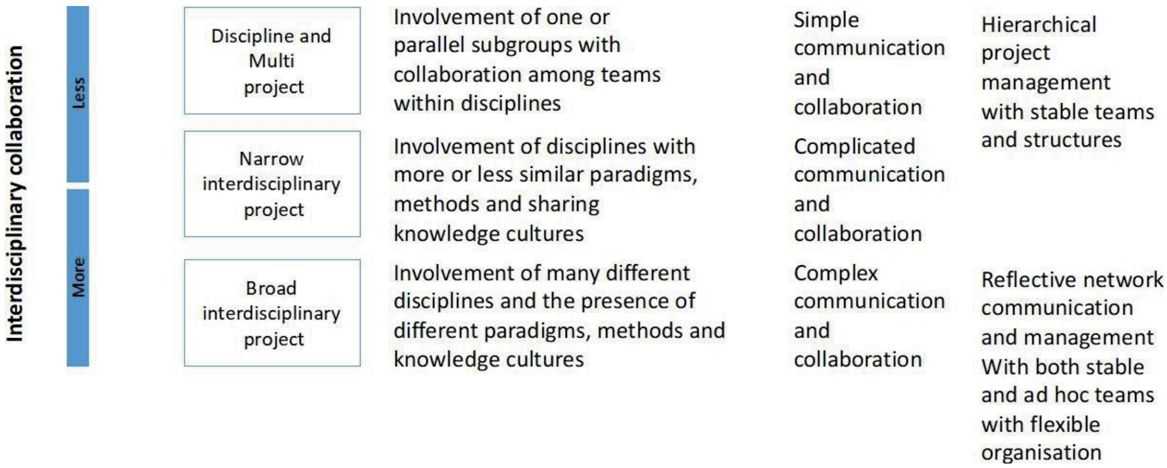

Figure 1: Types of interdisciplinary projects

The terms 'multidisciplinarity' and 'interdisciplinarity' are often used interchangeably in the literature. However, to understand variations in collaboration and complexity, we can benefit from a distinction between multidisciplinarity, understood as the cooperation of disciplines applied in parallel to a particular problem, and interdisciplinarity understood as the integration of discipline specific knowledge into one common project or solution (Klein, 2010; Szostak, 2004). Particularly within engineering education, interdisciplinary problem-solving will often result in a common product, and while the degree to which each discipline is integrated into the product will vary, all elements of the product will have to be adjusted to one other, which is considered a specific type of integration.

As illustrated in Fig. 1, another beneficial distinction can be made between narrow and broad interdisciplinary collaboration (Klein, 2006, 2010). Narrow interdisciplinarity covers collaboration within a shared knowledge paradigm with similar methods, while broad interdisciplinarity refers to collaboration across knowledge paradigms and scientific approaches. Within a narrow interdisciplinary team (such as chemistry, chemical engineering or biotechnology) a shared basic understanding of common methodologies, methods and data is more likely compared to a broad interdisciplinary team across e.g. humanities, social science and engineering with a larger variety of knowledge paradigms and thus increased complexity in the understanding, dialogue and negotiation of problems and problem-solving approaches. While collaboration and organization in any team, interdisciplinary or not, may bring conflicts and issues, a team collaborating across disciplines, compared to collaboration in teams with members from within the same discipline, is more likely to encounter difficulties in relation to understanding differences—e.g. in scientific paradigms and methodologies— and thus approaches to problem analysis and problem-solving. Furthermore, when the collaboration is of a considerable size (e.g. in 'teams of teams'), this can create challenges in how to organize work and collaboration across distance and time zones.

The team dimension refers to the number of students in one project. Smaller teams are usually considered easier to manage than bigger teams with more students. However, the type of discipline specific and interdisciplinary approach might add to the complexity of the project management and collaborative dimensions of the project regardless of how many students are involved in a project. Within traditional course structures, where the single discipline project is most common, the team size is usually about three to eight students working on a simple, single discipline problem in a project. For interdisciplinary projects, the number of team members will most likely increase, requiring the team (e.g. of eight to ten people) to reorganize in smaller sub-teams with specific parallel tasks and internal management processes both within and across all sub-teams working on the same project, making it a different learning experience compared to a single group working on a single-discipline problem.

2.1 Project Variations

Within the two dimensions, interdisciplinarity and team size, four basic project types can be identified; the *single discipline project*, the *multi-project*, the *interdisciplinary project* and the *megaproject*. This distinction of four project types is made for prescriptive purposes: real-life practice would provide more variations.

The *single discipline project*, usually carried out in a single project group, is well known and the most widely used both at course and curriculum level, where students within the same educational programme apply knowledge, theories and concepts to a simple discipline specific problem. An example can be a group of students applying control theory while developing an anti-sway system for a ship to shore crane.

The *multi-project* is less common and occurs in bigger courses or clusters of sub-disciplinary courses, and is characterized by a number of project groups working on the same or complementary elements (work packages) within the same or similar disciplines— e.g. in software development, or when groups work in parallel on the optimization of prototypes. These types of projects emphasise coordination among project teams to ensure the quality and feasibility of the common product and/or problem-solving methods. An example is computer science students optimizing an app for children with autism (AAU multi-project, 2020).

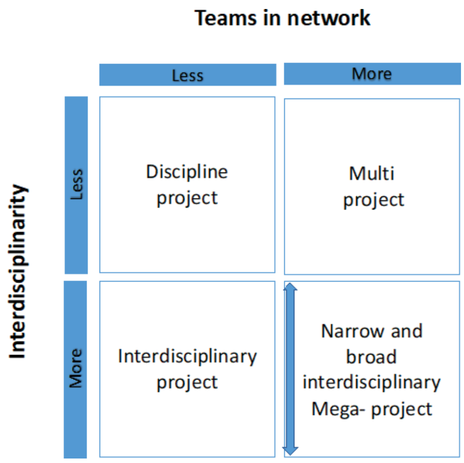

Figure 2: Ideal types of projects

The *interdisciplinary* project can be carried out in one project group of minor size. The team can be composed of students from different disciplines but can also be students from the same programme taking on an interdisciplinary approach to a particular problem or which is supported by a team of interdisciplinary staff members. For instance, in engineering projects, the preliminary problem analyses are often interdisciplinary in terms of academic scope, as students use e.g. sociological methods or participatory action research to identify user needs, allowing interdisciplinary knowledge to be integrated into a project with students from the same educational programme. An example can be students for media technology designing a sustainable city game for primary school, for which they need to have knowledge of both learning in primary shool, sustainable cities and game design.

The *megaproject* has recently been introduced into engineering education as something new (AAU, 2020). The general term 'megaproject' covers large, long-term and highly complex interdisciplinary projects (broad or narrow), normally characterized by a large investment commitment in development and implementation mostly by public funds, (infrastructure projects in cities, logistics such as high speed trains, aircrafts and airports, space technologies and renewable energy systems etc.) and great collaborative complexity (especially on an organizational level), with a long-lasting impact on the economy, the environment and society (Priemus, Flyvbjerg, & van Wee, 2008; Hu, Chan, Le, & Jin, 2015). Many future megaprojects will respond to global crises such as that of the COVID-19 pandemic and the grand challenges related to climate change and the UN Sustainable Development Goals (SDGs), which can be challenging to integrate into education; thus a framing of societal megaprojects to feasible educational megaprojects is necessary.

2.2 Megaprojects in Engineering Education

To frame the concept of megaprojects to be applicable within engineering education, we argue that it is necessary to work with the concept of 'black boxes' in the megaproject, with systems, or parts of a system, only considered in terms of inputs and outputs. Black boxing thereby refers to the process through which users (in this case engineering students) can have a general understanding of the system and its function without necessarily knowing all of its specificities. An example could be working with electricity grids and how to store energy from wind turbines, while not necessarily knowing the details of the wind turbine itself. In engineering, this is a well-known phenomenon, and to be able to bring real world problems and grand challenges into engineering education, this is a necessary part of the megaproject design. Advantages of this approach includes students learning to analyse relations in a system and to situate their specific knowledge, design or product within the overall system as well as an overall understanding of its relation to other disciplines beneficial for future interdisciplinary collaboration.

Since megaprojects require more resources than are usually available within a course or semester project, as well as more time to mature scientifically, technically and socially, it will be necessary to operate not only with black boxes in a system, but also with 'black phases'. Here, we refer not to a black box in the technological system, but instead a black box in the process of engineering. Most likely, students are part of just one or a few project phases—e.g. problem identification, problem analysis or problem-solving—essentially subjecting other project phases to black boxing, through which students hand over the results of a specific project phase to another team to continue the work into the next semester.

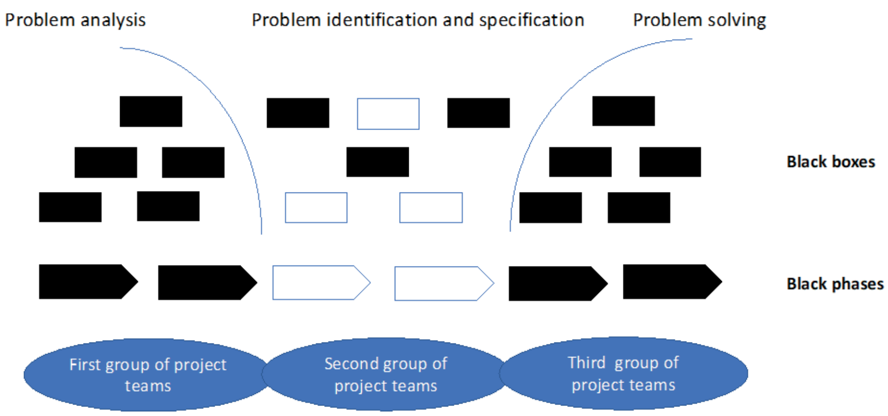

Figure 3: Black boxes and phases in projects

The phases can be defined and overlap in different ways; however, overall the process can be divided in two comprehensive phases: the *problem* phase, consisting of problem analysis and identification, with the aim of reaching a requirement specification; and the problem-*solving* phase, with the aim of develop a solution to the identified problem. Thus, when megaprojects run for several semesters, the first cohort of students works on the initiation, analyses and definition of the problem, while the second cohort works on requirements as part of the definition and design phase, and so on. The phases are equally important, and through experiencing different projects, students accumulate learning experiences related to all phases.

In a megaproject, a phase is not necessarily running for a single semester. Sometimes problem analyses or solving is done in iterations or for a longer periods of time, and for each phase several project groups join, These project groups might work on various tasks which will represent various credit points and thus with different workloads.

While a megaproject can be a feasible way to address complex problems such as those defined by the SDG's, there are many inter-related problems and a broad solutionspace. In this sense, the megaproject helps shed new light and new perspectives on challenges where we do not yet have a full understanding of the problem or limited current technical solutions to address it. While the students are expected to take a certain perspective in a megaproject and work only in one phase (e.g. problem analysis) in detail, it is considered a core competency to be able to understand and contribute to the alignment of different phases in the particular megaproject to help maintain an overview. This is particularly relevant when educational megaprojects relate to and collaborate with real-life megaprojects and external partners, either involving student projects over longer periods of time with several student teams and clusters involved, or where students work e.g. on one specific requirement in a sub-project but still need to understand its relation to other phases, as well as the overall aim of the project.

2.3 Interdisciplinarity in Megaprojects: A Spectrum

Whereas real-life megaprojects are most often considered broad in terms of interdisciplinarity, educational megaprojects can be modelled within a narrow inter-discipline scope, e.g. by dividing certain phases of the project across semesters. One such example is the AAU satellite project, which started up at the Department of Electronic Systems at Aalborg University. The project combine electronics and physics (space science) to build a fully functional satellite, and it has run through several phases, each corresponding to one semester (Larsen, Nielsen, & Zhou, 2013). In comparison to other narrow interdisciplinary megaprojects, this project is unique in adding a further 'product in operation' phase to the usual development of models and prototypes in PBL projects (Larsen et al., 2013; Zhou, Kolmos, & Nielsen, 2012). Another example is AAU Racing, where students, with a few exceptions, design all parts of a racing car. The product of each project is developed into a prototype and, in some projects, the engineering design is supplemented with a business plan and cost analysis (AAU Racing, 2020). There are many more variations and options, but characteristically, for the more narrow interdisciplinary megaprojects in engineering education, the focus is on a common product.

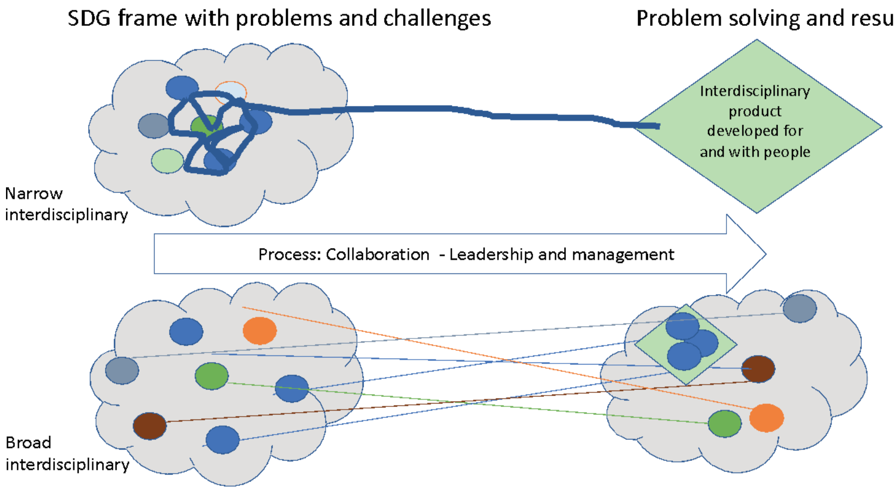

Figure 4: Types of narrow and broad megaprojects

The broad interdisciplinary megaproject that involves multiple disciplines, like the narrow, can span several semesters. For example, at AAU the megaproject 'Simplifying Sustainable Living' spans two years (AAU, 2020), with different focus areas highlighted (e.g. waste, green consumption and transportation). The first phases can involve identifying, analysing and even redefining a complex problem (for instance, the challenge 'Eat Locally' was renamed 'Eat Sustainably' as project groups found that locally produced food and sustainability did not necessarily correlate). Other phases can focus on specifying criteria for solutions, potentially defining additional narrow interdisciplinary megaproject proposals.

Compared to narrow interdisciplinarity, the broad interdisciplinary megaproject has a more complex organization, combining multiple disciplines that do not necessarily share the same knowledge paradigm, scientific methods or even scope. Thus, while an engineer and a social scientist may disagree on knowledge definitions and methodologies, it is much more critical if one understanding of the problem and aim of a sub-project within a megaproject conflicts with, or even counteracts, the aim of another. Therefore, even though the problem and solution phases and their products (black-boxed or otherwise) are equally important in broad interdisciplinary megaprojects, they must be modelled to , emphasise the precise contribution of different (and perhaps even conflicting) academic approaches and perspectives to improve and nuance the project's success criteria. The endpoint is a combination and interrelation of different systems, rather than one specific common product.

2.4 Complex Problem-Solving in Varying Project Types

Complex problem-solving competencies can ideally be achieved in all complex project processes, including discipline-oriented multi-projects as well as narrow and broad interdisciplinary projects (Attri 2018). The following Table 1 outlines the variation in some of the complex problem-solving competencies. Moving from left to right in the table, there is an increase in complexity in the contextual scope of the problem analysis, as well as the approach to design innovation.

	Disciplinary approach	Narrow interdisciplinarity	Broad interdisciplinarity
Project types	Discipline and multiprojects	Interdisciplinary projects Narrow megaprojects	Broad interdisciplinary megaprojects
Problem analysis	Understanding the problems in the discipline domain and how the discipline relates to other disciplines	Understanding problems related to parts of a system or parts of a process by combining a few core disciplines	Understanding problems in a comprehensive system perspective by making a synthesis of different discipline approaches
Problem-solving	Incremental product/service innovation (redesign what is)	Product/service innovation (design to substitute)	System innovation (design to change)
Project management	From stable teams and structures - to - agile systems/flexible structure with ad hoc groups		
Collaboration	From simple collaboration within same knowledge paradigm - to - difficult collaboration with different knowledge paradigms		

Table 1. Combining problem-solving competencies and project types

Table 1 stresses that increased complexity in problem-solving not only influences the content dimension, but also complexity in terms of collaboration and project management processes. The collaboration and organization of the project groups can vary greatly from having a simple and fixed structure of coordination to one that is fluid with emerging ad hoc groups and a focus on agile project management methods to involve more sub-teams in decision-making processes. However, as the complexity increases from a complex discipline specific project to narrow and even a broad interdisciplinary project, the need for agile systems and flexible structures increases due to the increased uncertainty related to both knowledge domains and potential solutions.

3 Final Remarks

In this paper, we have presented a project typology based on two dimensions: 1) the scientific content and problem scoping, ranging from simple and complicated problems to complex and interdisciplinary problems; and 2) the size and organization of the team(s) implicitly involved in project management processes on varying levels. Combining these two dimensions results in four ideal types of educational project categories: *single discipline projects, multi-projects, interdisciplinary projects* and *megaprojects*. We relate this to the distinction between narrow and broader interdisciplinarity and propose different variations including discipline specific multi-projects with several groups; the narrow one-group interdisciplinary project; the narrow interdisciplinary megaproject across groups (narrow by black-boxing parts of the system/processes); and the broader interdisciplinary megaproject across groups, including a comprehensive system perspective.

While the problem and solution phases of the project are obviously closely linked to the content, the learning potential is very much linked to the generic competencies obtained through interdisciplinary project work, both in terms of problem analysis, problem solving, collaboration and project management. The broader the disciplinary team constellation is in a multi- or megaproject, the more emphasis is put on students' complex problem-solving and collaboration competencies within and across groups. Furthermore, in comparison to narrow interdisciplinarity, a broad interdisciplinary approach will challenge the students to understand and communicate the qualities and contributions of their own discipline, as well as its boundaries and interaction with other disciplines.

In this paper, we have presented an overall conceptual framework for project types and complex problem solving competences. Future work includes studies to elaborate on the dimensions of the different project types, and explore how the framework can be appropriated to different problem solving competences e.g. entrepreneurial competence, business competence or digital competence.

Educational megaprojects combine the challenges of complex technological systems and complex collaboration patterns, and this type of project can be seen as bringing together competencies from other types of projects and adding both a societal and an intercultural dimension to the learning experience. Compared to the great challenges of our time, living in what has been coined a 'global village', where citizens struggle to obtain sustainability, the broad interdisciplinary megaproject holds a consolatory prospect for future engineering education.

4 References

Aalborg University. (2020). *Megaprojects*. Retrieved from https://www.megaprojects.aau.dk/

AAU Racing. (2020). *AAU Racing.* Retrieved from https://aauracing.dk/

AAU multi-project. Retrieved from https://giraf.cs.aau.dk/
http://people.cs.aau.dk/~ulrik/Giraf/Projects2012/Oasis_sw604f12.pdf

ABET. (2014). *Criteria for accrediting engineering programs.* Retrieved from http://abet.org/eac-current-criteria/

Algreen-Ussing, H., & Fruensgaard, N. O. (GASAT Conference (19 : 1990 : Jönköping)., Granstam et al.). *Metode i projektarbejde. Problemorientering og gruppearbejde*. Aalborg Universitetsforlag, Aalborg.

Attri, R. K. (2018). *Accelerating complex problem-solving skills: Problem-centered training design methods.* Retrieved from https://www.speedtoproficiency. com/blog/problem-centered-methods/

Chen, J., Kolmos, A., & Du, X. (2020). *Forms of implementation and challenges of PBL in engineering education: A review of literature. European Journal of Engineering Education*, 1-26. doi:10.1080/03043797.2020.1718615

Dreyfus, H. L., & Dreyfus, S. E. (European Conference on Women Natural Sciences & Technology : 1986 : Helsingør). and Dahms). *Mind over machine: The power of human intuition and expertise in the era of the computer*. New York, NY: Free Press.

Fraser, D., Allison, S., Coombes, H., Case, J., & Linder, C. (2006). Using variation to enhance learning in engineering. International Journal of Engineering Education, 22(1), 102–108.

Holgaard, J. E., Søndergaard, B. D., & Kolmos, A. (2019). *Guide og katalog til PBL progressive læringsmål.* Retrieved from https://vbn.aau.dk/ws/portalfiles/portal/311379922/PBL_progressive_l_ringsm_l_guide_final.pdf

Hu, Y., Chan, A. P., Le, Y., & Jin, R.-Z. (2015). *From construction megaproject management to complex project management: Bibliographic analysis.* Journal of Management in Engineering, 31(4). doi:10.1061/(ASCE)ME.1943-5479.0000254

Jonassen, D. H., Strobel, J. and Lee, C. B. (2006). *Everyday Problem Solving in Engineering: Lessons for Engineering Educators*, Journal of Engineering Education, Vol. 95, No 2.

Jonassen, D. H. (2010). *Learning to solve problems: A handbook for designing problem-solving learning environments*, Routledge.

Jonassen, D. H. and W. Hung (2015). *"All problems are not equal: Implications for problem-based learning."* Essential readings in problem-based learning, 7-41.

Klein, J. T. (2006). *A platform for a shared discourse of interdisciplinary education*. Journal of Social Science Education, 5(4), 10–18.

Klein, J. T. (2010). *A taxonomy of interdisciplinarity*. The Oxford Handbook of Interdisciplinarity, 15, 15–30.

Kolmos, A. (Johansson, Larsson et al.). *Progression of collaborative skills*. In J. Conway & A. Williams (eds.), *Themes and variations in PBL, Vol. 1*. Refereed proceedings of the 1999 biennial PBL conference, 7–10 July 1999, Montreal, Canada.

Larsen, J. A., Nielsen, J. F. D., & Zhou, C. (2013). *Motivating students to develop satellites in problem and project-based learning (PBL) environment*. International Journal of Engineering Pedagogy, 3(3), 11–17.

Pang, M. F. (Peterson, … et al.). *Two faces of variation: On continuity in the phenomenographic movement*. Scandinavian Journal of Educational Research, 47(2), 145–156.

Priemus, H., Flyvbjerg, B., & van Wee, B. (2008). *Decision-making on mega-projects: Cost-benefit analysis, planning and innovation.* Edward Elgar Publishing.

Snowden, D. J. and M. E. Boone (IPCC). *"A leader's framework for decision making."* Harvard business review 85(11): 68.

Szostak, R. (2004). *Classifying science: Phenomena, data, theory, method, practice.* (Vol 7). Springer Science & Business Media.

Zhou, C., Kolmos, A., & Nielsen, J. F. D. (2012). A Problem and Project-Based Learning (PBL) Approach to Motivate Group Creativity in Engineering Education. *International Journal of Engineering Education*, *28*(1), 3-16. http://www.ijee.ie/contents/c280112.html