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Variation of PBL in Higher Education Within Engineering, Science and Mathematics*

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Aalborg University (AAU) in Denmark is one of the universities in the world that practises problem-based learning (PBL) in all study programmes at all faculties. The PBL principles are broadly defined, and each study programme practices PBL in its own way within these frames. In this paper, we study how differently PBL is practiced within the science, engineering and mathematics areas at AAU. In particular, we analyse 21 AAU Bachelor theses in a selection of different engineering, science, and mathematics study programmes, to explore which types of problems from the discipline the students are addressing in their projects. We exemplify this through an analysis of recent Bachelor theses from Chemical Engineering and Biotechnology, Building and Construction Engineering, Mechanical Engineering, Mathematics, and Biology, respectively. The focus is on which types of problem from the discipline the students work with. The research methodology is documentary analysis of curricula and the theses. We first, through a deductive analysis, apply the four shadows of problems' theoretical framework to categorize the problems. This showed that 18 of the 21 theses can be categorized as concerning a contrast problem. This is the case for all five fields of study. Secondly, a more detailed inductive content analysis of these 18 theses' problems showed that these 18 problems had a great variation, and we were able to identify five specific types of contrast problems among these 18 theses.

Keywords: Bachelor thesis; problem-based; problem variation; project work; engineering, science and mathematics education

1. The Nature of Problem-Based Learning

Problem-based learning (PBL) has been practiced all over the world since the seventies. As example, Aalborg University (AAU) in Denmark has, since it was established in 1974, organised all curricula at all faculties around the principles of project- and problem-based learning, uniting project-based and problem-based learning. In problem-based learning, students choose an open-ended, ill-structured, and authentic problem, and this problem is narrowed down through an analysis to a solvable problem stated as a *problem formulation*, and the students develop a viable solution or answer to this problem, e.g., a design, a model, a tool, a plan etc. The practice of PBL at AAU has undergone several changes [1, 2], but the PBL *principles* have not changed substantially. The most recent official formulation [3] states six PBL principles:

(1) The *problem* is the point of departure and guideline for the project work.
(2) The *projects* are organised in groups of usually max. seven students and only occasionally do students work alone.
(3) The projects are supported by *courses* that often are scheduled frequently in the beginning of a semester to allow for more uninterrupted time for the project towards the end of the semester,
(4) *Collaboration* with a supervisor who acts as a facilitator, and sometimes collaboration with external partners and/or other groups;
(5) *Exemplarity*, which means that the project's learning outcomes can be transferred to similar professional problems.
(6) *Students* are responsible for their own learning and organise the work themselves, which means that the supervisor is not the project leader.

The problem formulation is developed through a problem analysis of an initiating ill-defined problem chosen within a prescribed semester theme and it is often selected among different options provided in a project catalogue developed by the supervisors. The project usually accounts for 15 ECTS (European Credit Transfer System, where 30 ECTS is a full semester) while the other half of the semester consists of courses that support the project. A PBL introductory course is taught during the first semester [4]. This course focuses on what a problem and a problem analysis is, but also includes process competencies such as conflict management and time planning.

The identification and formulation of the problem is demanding for students and has special attention of the supervisors. Put another way by Hung, the problems are "the critical essence in a student's learning process and achievement of the learning goal" [5, p. 249]. Thus, they are "a critical and significant component of the instruction in student learning throughout the PBL process"

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(Ibid). It also means that the nature of the problem defines which theories and methods can be used for problem understanding and problem solution [6, p. 9]. Despite more than 40 years of practice, it is therefore still necessary to further explore the nature of and types of problems used in PBL practices especially seen in the light of an increasing demand for interdisciplinary collaboration in real life problem solving.

The PBL *principles* do not impose a fixed *model* but allow for flexibility and the practical implementation of PBL, even within engineering, science, and mathematics (disciplines which are relatively close), varies [7]. This is true to the principle of exemplarity as each education programme should be relevant to the students' future profession, but it also raises the question of where the "border" of PBL lies. Hence, there is a need to look deeper into the types of problems within PBL in the engineering, science, and mathematics disciplines to identify those, who are "most amenable to PBL" [8, p. 26], and vice versa to explore "the amenability of PBL methods to different kind of problems" [8, p. 18]. Two reasons should be highlighted here, the pedagogical one for further developing didactics in a PBL perspective, and second for improving the quality of teaching by developing more knowledge about problem types, and thus "the quality of problems" [9, p. 7].

It is important to achieve a deeper understanding of the various problem types in order to meet the requirement of e.g., interdisciplinarity in the problem definition and problem solution phase. The research question for this paper is therefore: Which types of problems in engineering, science, and mathematics do students address in their Bachelor theses? Five study programmes were examined (see Methodology for details).

In the PBL literature, the prominent role of problem design on "the effectiveness of PBL courses and curriculum" is pointed out [5, p. 249]. Our focus is on forms of appearance for types of problems within different engineering, science and mathematics disciplines, therefore is at a micro level of PBL, which has implication for PBL at the institutional system level as the different parts, from the perspective of system theory, are "dynamically interrelated and cannot be understood in isolation from the whole" [10, p. 41]. According to Savin-Baden, the categorization of different PBL approaches and practices include i.e. "problem type, form of interaction, knowledge focus . . . , form of facilitation, focus of assessment, and learning emphasis" [11, p. 2]. Ergo, how problems and projects are being implemented affects, and is affected by, how PBL is/will be described in the curricula as well as how supervision takes place affect what and how students learn. However, for this paper our focus in solely on further classification of problem-types and how they appear in selected engineering, science, and mathematics disciplines. Reinholz et al. argue that "STEM disciplines remain highly siloed" [12, p. 2], and for that reason do not sufficiently fulfil future requirements in society. Therefore, a reform of STEM (science, technology, engineering, mathematics) higher education is needed. A precondition is to "facilitate crossdisciplinary . . . learning, and collaboration" [12, p. 2] in STEM higher education, to which our article will contribute.

2. Theoretical Framework on Types of Problems

This paper builds on the work of [7] and is based on a similar theoretical framework that has been further developed in this paper. The role of the framework is to guide the data collection and analysis.

In engineering, PBL mostly originates in practical problems in areas such as transport, health, and sustainability. According to [13], a practical problem becomes theoretical when we ask 'why' the practical problem has happened, and theoretical problems often arise from the contradictions that one experiences in the confrontation with practical problems. A practical problem is a contradiction between what you want and what you can do, while a theoretical problem is a lack of understanding you know that you have [13]. Engineers also work with pure theoretical problems, such as turbulence in fluid flows in mechanical engineering. Here, theoretical problems may have originated in scientific theories, more specifically in scientific laws. In science, a problem could be a knowledge problem that initiates the learning process, for instance a description of a natural phenomenon, and the PBL student group should, as stated by de Graaff, then find or provide an explanation of that phenomenon that satisfies the scientific criteria of the specific discipline [14]. These problems can both be theoretical and practical. In mathematics, problems arise in three different contexts (or communities): daily everyday life, professional or practical context such as in the vocational or engineering fields, or in the research society among researchers of pure or applied mathematics. These problems can also be either theoretical or practical [15].

Jonassen and Hung [8] discuss that PBL problems can be situated on two axes, a well-structured versus ill-structed axis, and a simple versus complex axis. They describe several different problem types. We find the description of the two axes very relevant for describing PBL problems and we will return to this in the discussion. However, some of the types of

PBL problems described in [8] do not appear to be directly applicable to engineering, science, and mathematics education, e.g., 'policy analysis problems'. Others can be related to these disciplines, e.g., 'decision-making problems' or 'design problems', but the description of these problems are at a more general level. We found a more detailed conceptualization of PBL problems in the framework entitled the "four shadows of problems" [16, p. 1072] by Holgaard et al. which describes four archetypes of problems: *anomaly*, *paradox*, *contrast*, and *contradiction*. These four types are interpreted in slightly different ways in the literature. Below we provide descriptions adapted to the fields of engineering, science, and mathematics as the framework was not directly developed to this context. An anomaly is an exception from the rules/norms that "appears in a way, which differs from what we had expected" [17, p. 81] and fit projects concerned with unexpected or surprising observations. A paradox is "two sets of facts meeting in contrast" [16, p. 1072], or it is an "anomaly that also problematises existing perceptions/theories" [18, p. 35]. This could be projects concerned with explaining or solving situations where something happens that ought not to happen. A contrast is "a tension between two conditions that is the desired and the actual condition" [16, p. 1072], or "between a situation of status quo and a possible other situation – a vision" [17, p. 89]. This, we find, is seen in e.g., optimisation projects. A contradiction is "a simultaneous statement or relation which mutually excludes each other" [16, p. 1072]. Thus, it is stronger than an anomaly, and includes phenomena where condition *a* excludes condition *b*, vice versa. In the theses, problems are stated as *problem formulations*, which usually end up with a form of question, yet a question might not in itself be a problem formulation: "There are many questions in the world, only some of them are problem formulations" [18, p. 31]. The problem formulation puts focus on an unsolved problem while it relates to existing knowledge and articulate unknown knowledge. [8, p. 9] refer to this as the dimension 'complexity' addressing "the known portion of the problem" and dimension 'structuredness' dealing "with the unknown portion of the problem". Also, we point out, in themselves, the problem formulations do not impose a specific course of action or methods for a project, and similar problem formulations can be answered using various methods, e.g., if different theoretical frameworks are chosen.

3. Research Methodology

The analysis is an extension of work done in [7], to which we added two more programmes. In the present paper, we analyse 21 recent Bachelor theses (6th semester) from the following five study programmes in engineering, science, and mathematics: Chemical Engineering and Biotechnology (three), Building and Construction Engineering (four), Mechanical Engineering (seven), Mathematics (three), and Biology (four), respectively. The students are then at their 6th and final semester of a three-year Bachelor programme (in Denmark, bachelor's degrees are 3-year programmes). Many students would later continue to study a master's degree (two more years of study) either at AAU or another university, or find a job. Bachelor theses therefore show how students practice their subject by the end of a separate study programme with its own curricula and learning objectives. Since the AAU Bachelor programmes have a very high focus on PBL from the first semester, we expect to avoid "beginner-issues" in PBL as the Bachelor thesis is the seventh PBL project at AAU (it is the seventh project since the first semester includes two PBL projects). We reviewed the five most recent years at the time when we began our research (2015-2019) to find a year in which there were at least three Bachelor theses in all five programmes. This number (three) makes it possible to see some span of theses and secure, to some extent, the anonymity of the students. Studying theses from the same year also means that the students have received similar PBL introduction the first semester. Based on this, we chose 2017 and analysed all available Bachelor theses in the five above mentioned study programmes.

We accessed the Bachelor curricula either on the university website or received them from study secretaries and all submitted student reports at AAU can be found on an internal database accessible to all staff. We use document analysis as a qualitative research method to analyse the curricula and the Bachelor theses. The main characteristic here is a lack of researcher intervention in the documents to be analysed [19]. The abstract definitions of the four types of problems can sometimes be difficult to recognise in practice [16], wherefore the two authors analysed the stated problems in their contexts in the theses. The first analysis of the 21 theses was a deductive analysis applying the four shadows of problem. This analysis yielded that 18 of the 21 theses involved a contrast problem (see Table 1). Partly due to the large number of one specific problem type, partly since we considered these 18 theses to be quite different, the second analysis further conceptualised the 18 contrast problems to expand the original framework of the four shadows of problems. We here did a careful and more inductive content analysis with open coding until some conceptual components emerged (see Table 2). In practice, this part of the analysis took part in the following ordered seven steps:

(1) We took outset in four of the 18 theses and discussed how to code these here agreed on some examples of codes.
(2) Each author then separately coded all the theses using these codes. Furthermore, each author made suggestions to additional codes.
(3) We met to compare, discuss, and finalise codes for five theses, including the first four. Most of our new suggested codes were identical, other times we agreed to a code. For instance, one of us used the code 'compare' while the other used 'choose' when coding a thesis. Here, we had noticed the same essence, namely that through a *comparison* of solutions, the group wanted to *choose* between different solutions. We here agreed to use the code 'compare' for such occurrences. Other times a discussion led to a refinement of a code, for instance at some point we had a code called 'knowledge'. However, sometimes 'knowledge' referred to students learning something which is new to them, other times it referred to the fact that the field has not yet developed knowledge in a specific area. We therefore divided 'knowledge' into two codes: 'learn knowledge' and 'knowledge gap', respectively.
(4) Each author separately recoded the remaining theses. This phase was repeated twice, and three times in cases of doubt.
(5) We met and agreed to the final codes and made Table 2 showing all the codes indicating which thesis had received which code.
(6) Each author separately analysed Table 2 for patterns and emerging commonalties among the 18 theses with a contrast problem.
(7) We met and discussed the emerging types.

The codes developed are all seen in Table 2, left column.

4. Analysis of 21 Bachelor Theses and Curricula

Overall, when we analysed the Bachelor curricula for all five education programmes [20–25], we saw that PBL was clearly articulated as general skill learning goals but also more specifically as either Bachelor theses skills or competencies. For instance, concerning skills for the Bachelor theses in Chemical Engineering and Biotechnology, students "must be able to develop a problem analysis which clarifies the 'critical points' of the problem" [23, p. 39]. For further description and analysis of some of the curricula, we refer to [7].

The description of the problems of the 14 theses that was also analysed in [7] is comparable to this paper, but on some occasions revised because of a more in-depth analysis (see below for details). The description follows a certain structure: A) title, B) challenge or problem area description, C) problem formulation (PF) or research question (RQ). In a few cases the description differs from this categorization, for example by the use of aim/purpose instead of challenge/problem area description, or by not applying PF or RQ. Whenever titles and specific problem formulations are not in English, we have provided a translation.

4.1 Chemical Engineering and Biotechnology

As can be seen below, all groups are 1-person groups, which is unusual at AAU due to the PBL principles of collaboration. However, sometimes for practical and personal reasons (few students in cohort, prior illness, personal circumstance etc.) 1-person groups are allowed. The three theses below were submitted with several months between them during 2017, but the specific reasons are not known to the authors.

Project 1. (A) Title: *The effect of microwaves on the organic dye RNO through activation of persulfate* (1 student, 74-page report). (B) Challenge: The outset is the problem of increasing population of the earth and industrialization causing the hydro sphere to be increasingly polluted with organic and non-organic material. This leads to the initiating problem: "Which oxidation methods can be used to treat organic pollution?" (C) PF: After discussing various methods, the thesis states the following problem formulation: "Can persulfate be activated through microwave irradiation and what is the importance of time, temperature, concentration of the solvent, and the strength of the microwaves?" This thesis clearly applies PBL terminology. The problem is contrast as it deals with a desired and actual situation.

Project 2. (A) Title: *Three-Dimensional Electrode Reactor for Wastewater Treatment* (1 student, 65-page report). (B) Challenge: Wastewater is explained as being produced by many sources and wastewater must be treated to adequate levels before releasing it to the environment to preserve the cleanliness of natural water bodies. Tertiary treatment is necessary to mineralize these organics. (C) RQ: The problem is stated as a research question: "Are 3D electrode reactors more efficient and economically feasible for removal of low concentration organic pollutants from wastewater than simple 2D processes?" This problem is a contrast problem as it looks for a better way to handle wastewater.

Project 3. (A) Title: *Production optimization of pigments extracted from the fungi F. solani* (1 student, 45-page report). (B) Challenge: The thesis does not define a problem area but has outset in the cultivation of the *Fusarium solani* fungi with the purpose of production and extraction of pigments through the fungi's secondary metabolism. (C) PF: "In connection with this project, a production optimization and up scaling of pigments extracted from *F. solani* is desired. It is desired to find the best suited medium for pigment production, and then how this production in the best way can be upscaled". Although not stated as a problem, it is a contrast problem dealing with optimization.

4.2 Building and Construction Engineering

Project 1. (A) Title: *Establishment of new waterworks near Lundby Krat* [forest] (5 students, 110-page report). (B) Challenge: The winning of drinking water directly from the groundwater is challenged by increasing pollution from nitrate and pesticide. In Aalborg Municipality, a buffer on available water resources of 25% should in future be a reserve against pollution and closure of water wells. (C) PF: "How to establish a new waterworks with associated source sites in Aalborg Municipality, where nitrate levels do not pose a future challenge?" This problem formulation is concretized with six sub-questions. The problem is a contrast problem as it deals with an actual, practical, and desired situation.

Project 2. (A) Title: *Expansion of Tranholm road* (4 student, 156-page report). (B) Challenge: Based on a traffic model from Aalborg Municipality, the purpose of the thesis is "to create a solution that can sufficiently handle future traffic amounts and sustain a sustainable traffic flow". The background is an expected increase in the traffic volume in the eastern part of the growth axis around Tranholm road. (C) PF: "How should the extension of Tranholm road be designed so that the road can handle the load in 2030?" As above, the problem is a contrast problem for similar reasons.

Project 3. (A) Title: *City Park houses* [Byparkhusene] (5 students, 272-page report). (B) Challenge: Existing architectural drawings and drilling rigs for dimensioning the construction pit enable the focus on the next step for the realization of the residential building. (C) Issue: Then, this issue (not problem formulation) results in the following three questions: "(1) How is the construction of the City Park houses' "raw house" organized, planned and priced? (2) How can the construction pit be designed so that it is kept dry, and collapse is avoided? (3) How can Byparkhusene be built as a concrete element building, so that stability and robustness requirements are ensured?" The thesis is therefore a technical challenge to the students, not to the field (professionals in the field already have the knowledge, the students have not) facing tasks within an ordinary production flow in the building industry. We term this new problem type *production flow problem*.

Project 4. (A) Title: *Assessment of hand versus FEM calculations' applicability to dimension reinforced concrete slaps* (1 student, 99-page report). (B) Purpose: The purpose is to compare methods in construction engineering, a FEM (Finite Element Method) programme and hand calculation methods with beam and plates constructions as examples. The FEM method is usable without knowledge of the theory and methodology behind the programme and can therefore give wrong results. (C) No PF: The thesis does not contain a definite problem formulation or research question. The thesis is done to illustrate the applicability of the methods and the difference between them. It compares different methods with a wish to find the best for different situations and is therefore a contrast problem.

4.3 Mechanical Engineering

Project 1. (A) Title: *Baseplate with adjustable stiffness* (4 students, 76-page report). (B) Challenge: The problem, introduced by a company, exists when customers install industrial pumps, and the foundation does not meet the necessary recommendations. The initial problem formulation is: "How can resonance in the working frequencies be avoided by constructing a baseplate with adjustable stiffness in relation to the foundation stiffness?" After a problem analysis, the group arrived at the following (C) PF: "How can a passive vibration isolator be designed to avoid excessive vibration levels on the foundation of a vertical pump system and how can the vibration isolators be altered so the stiffness of the baseplate can be adjusted?" This is a contrast problem because the students want to reach a better functioning product.

Project 2. (A) Title: *Design of a movable theatre lamp* (1 student, 55-page report). (B) Challenge: The thesis is based on a case from a local music venue with a wish to add flexibility to older, non-automated lamps. The purpose is to increase the management possibilities during the concerts by having movable lamps within a limited budget. (C) PF: "How can a PAR-64 lamp be modified so that the light beam can be moved and thus the lamp becomes an alternative to purchasing new lamps." The thesis e.g., established technical criteria for the dimensioning of construction and motors to apply to this local venue. As above, the problem is a contrast problem for similar reasons.

Project 3. (A) Title: *Design and Modelling of Planar 3-DoF Robot* (4 students, 175-page report). (B) Aim: The aim is to improve a three degrees-of-freedom system, a task the group was given by their supervisor. The focus was analysing a 3-DoF system by using a CAD model and finding possible improvements for the current system. (C) The PF: "How can a planar 3-DoF robot be designed and modelled so the workspace area and the driving forces of the system are improved?" This improvement of the product represents a contrast problem.

Project 4. (A) Title: *Design of Active Rear Wing for Formula Student Race Car* (3 students, 149-page report). (B) Challenge: There is no stated problem but *a wish to improve* an existing product, an AAU Formula student race car by designing a rear wing. The design was based on two active functions defined. (C) Problem statement: The named problem statement, which did not state a problem, was: "Design a rear wing for the AAU Formula Student racing car, which complies with . . . defined requirements." The thesis objective, the concepts of an active drag reduction system and an active braking system were presented as well as ways to actively implement the two systems, based on a strong theoretical work. Again, this is a contrast problem for similar reasons as above.

Project 5. (A) Title: *Development of Laser scanning system & Study of Laser Bonding* (4 students, 93-page report). (B) No formulated challenge: The thesis is part of the laser processing research in the students' department, dealing with the development of a system of high-speed laser processes. This has been worked on before, and two previous groups in previous years have designed a laser booth and procured the necessary equipment. (C) No formulated FF or RQ: This group wants to finish the work. The thesis deals with various topics related to this technical development project, for which the desired results are high speeds and thus a reduction of process times. It is a contrast problem as it deals with desired and an actual situation.

Project 6. (A) Title: *Energy consumption of 2 DOF robotic arms – Set up analytical tool* (4 students, 136-page report). The students state the relevance of streamlining industrial robots. (B) Aim: The aim of the thesis is to develop an analytical tool through which the influence of specified parameters on the energy required to power a 2 DOF planar robot arm can be studied. The investigation begins in a case, where the robot arm must be able to transport an object with a mass of 5 kg between two predefined coordinates in three seconds. (C) PF: "How can an analytical tool be developed to determine the lowest energy consumption of the motors, searching among the combinations generated when combining ranges of investigated design parameters?" In [7], we termed this a contrast problem, however, a re-analysis made us reconsider how to interpret the definition of contrast problem. We now judge the problem to be a specific engineering challenge. Hence, the problem falls out of the definition of the four shadows of problems as we also saw in Building and Construction 3. However, this problem is not a production flow problem. We term it as a – *domain specific problem*. They are solely focused on a narrow disciplinary aspect without consideration of application and context and the 'problem' more resembles a task problem. We will get back to this below and in the discussion.

Project 7. (A) Title: *Corrosion of helix tubes* (4 students, 92-page report). (B) Challenge: A problem, posed by a company, deals with corrosion of helix pipes in OC-TCi boilers. These boilers contain both straight tubes and helix tubes where the helix pipes corrode significantly more strongly than the proper pipes despite being in the same boiler water. This leads to the initiating problem: "What causes the helix embossed pipes to corrode before the proper (right) pipes?" (C) PF: After the problem analysis, the group stated the problem that the helix pipes corrode more than the right pipes, despite measures aimed at reducing corrosion in general. Therefore, their main question (C) RQ is: "What corrosion mechanism causes the helix embossed pipes to corrode before the proper pipes, and how can a possible redesign of the pipes meet this corrosion mechanism?" This thesis differs from the others. We face a paradox. Two different pipes corrode at various speeds, despite being in the same boiler water.

4.4 Mathematics

Project 1. (A) Title: *Analysing Wind Power Time Series Using ARIMA Models* (5 students, 95-page report). The introduction began by arguing that "global warming is an increasing problem in the world". This leads to a discussion of the application of renewable wind energy. It also explains that it is impossible to stock wind energy. (B) Aim: It then states: "The aim of this report is to examine whether the simple approach of ARIMA models provide sufficient models to forecast wind power, or whether more sophisticated tools must be applied". (C) No PF or RQ: This thesis clearly originates in a real problem as initiating problem; however, although the problem they work with is clear, it is not formulated as a problem but as an aim. This thesis works with a contrast problem as they envision a better solution than the present.

Project 2. (A) Title: *Time series and forecasting wind power* (5 students, 85-page report). (B) Issue: As in Thesis 1, the introduction discusses the issue of finding alternative energy sources. However, the report deviates from Thesis 1's report as it applies PBL terminology "problem analysis", "thesis statement", and "project delimitation". The content of the problem analysis is, however, quite like Thesis 1, both leading to an introduction of time series analysis of data gathered over time. (C) RQ: The section called 'thesis statement', asks: "Is it possible to use the theory behind time series to detect patterns in wind power produced and develop a method to forecast productions by using previous observations?" The delimitation section described more specifically, which types of time series analysis are used. This thesis presents a contrast problem.

Project 3. (A) Title: *Robotics Arms – An Application of Gröbner Bases* (3 students, 61-page report). (B) Problem area description: This thesis examines the forward and inverse kinematic problem for robotic arms in two and three dimensions. The report discusses that the industry uses robots and that the robotic arm consists of chains of segments and joints that make it possible to move the segments in different directions. The report states that these problems can "be described in different dimensions. For application in the real world, we consider the problem in three dimensions. However, for understanding the problem, we consider two dimensions since this is a simpler case". Thus, although the problem of the report originates in a real world, the report is theoretical, working mainly with two dimensions and the overall impression is a theoretical report. (C) No PF or RQ: The group does not specifically state a problem formulation. The reference to industry is not the driving force of the thesis as it is just mentioned one time, line 1 in the introduction. The problem is mainly a contrast problem as it deals with explaining how to better control robots. Although ME6 also deals with robotic arms, M3 is different as they are aware of the context and that they consider a special case in order to be able to know something relevant for the real word.

4.5 Biology

Project 1. (A) Title: *The influences of land use on water quality over different spatial scales – buffer zone versus catchment: A review* (3 students, 27-page report). (B) Purpose: The report was a literature study with the purpose of determining "whether the land use of the entire catchment or that of the buffer zone is more important in influencing the water quality can help improve land management practices, thus yielding a healthier water quality". Seventeen studies are compared. (C) No PF or RQ: The report does not state a problem; however, it is clear that the problem is how to secure healthier water quality. The report reveals that research does not yet know the answer as different studies have different conclusions. This appears to be a contrast problem as it focuses on a desired and actual situation.

Project 2. (A) Title: *The effect of macrophytes on nitrate removal in aquatic microcosms* (4 students, 14-page article). (B) Aim: The aim of the thesis is "to evaluate the effect of macrophytes on nitrate removal in aquatic microcosms". Moreover, the article states: "However, studies accounting for the effect of macrophytes on nitrogen removal and denitrification are lacking". (C) No PF or RQ: As above, the students do not mention the term "problem"; however, we see that their work originates as a scientific problem concerning the effect of macrophytes on nitrogen removal, where the research community still does not have sufficient knowledge. As above, the problem is a contrast problem for similar reasons.

Project 3. (A) Title: *Nutrient deposition from colonies of cormorants: A case study from Tofte Lake*" (3 students, 48-page report). (B) Purpose: The purpose is to investigate if a colony of cormorants contribute to the nutrient deposition in a lake. This may cause a deterioration of the aquatic environment, hence influence the water quality. The report states that some of the work was done in collaboration with another group (whose report was not in the system). The two groups collected samples together and afterwards shared the laboratory work. Both groups had access to all results. (C) No PF or RQ: This group does not state a problem formulation but formulate the aim of the report as to investigate the cormorant colonies' nutrient deposition to nearby lakes. The problem is, however, easily discernible as threats to water quality. Tofte Lake is their case. In order to assess the amount of nutrient deposited, they list three hypotheses to test. For instance: "there is a significant higher conductivity and concentration of phosphor and nitrogen and a significant lower pH-value in the soil in the area around the cormorant colonies compared to a control area". These hypotheses are not problem formulations but derived from the problem. They appear to be part of the method of the thesis. As above, the problem is a contrast problem for similar reasons.

Project 4. (A) Title: *Eelgrass in the Limfjord [fiord]: growth and sediment* (1 student, 19-page report). (B) Challenge: This thesis is a literature review of the problem of eelgrass having "been subject to changes in its natural growing habitat". These changes have resulted in the sediments becoming muddy with low light intensity in large areas of the Limfjord. (C) No PF or RQ: The thesis wants to illuminate which factors affect the spread of eelgrass and summarises various laboratory or field experiments and theories. The overall impression is a theoretical report. This thesis uses the term "problem" to describe the purpose. As above, the problem is a contrast problem for similar reasons.

5. Analysis and Discussion of Types of Problems

In this section we will describe the result of our analysis of the 21 bachelor theses and the emerging types of contrast problems.

5.1 Overview of all 21 Bachelor Theses

Table 1 shows which types of problems the 21 bachelor theses deal with, analysed from the four shadows of problems (anomaly, paradox, contrast, contraction). Two new problem types emerged that did not belong to any of these four.

Specifically, about the two new categories: We discussed if two theses (BE3 & ME6) were "weak" versions of contrast problems or categories by themselves. They were clearly not anomaly, paradox, or contradiction problems. BE3 was named production flow since the students on their own repeated the steps that a real building entrepreneur had done in the past based on documents and drawings from an existent building production. From these drawings, the students developed all the steps in the production necessary for maturing the building process. This was documented in their report. ME6 focused on a specific and narrow technical engineering challenge without any focus on the context of the problem. On the one hand, these theses were not an improvement of something existing, a vision or something else usually characterising contrast problems. On the other hand, when producing something, the purpose is in the long run to serve the need of someone – ergo indirectly a vision/improvement. We concluded that this would be putting too much elastic into the definition of contrast problems – almost everything would then be a contrast problem. Hence, we decided to form these two new categories. We return to these categories in the discussion.

5.2 Dividing the 18 Examples of Contrast Problems into Five Types

As stated in section 3 (methodology), the 18 theses identified with a contrast problem were quite different. Therefore, the second analysis did a more inductive content analysis to further conceptualise the 18 contrast problems, which resulted in identifying five specific types of contrast problem. Table 2 gives an overview of the 18 bachelor theses with a contrast problem, showing which of the developed codes each thesis was assigned with during the analysis. The letters indicate different types of contrast problems.

Since none of the 18 theses were coded in identical ways, but some theses appeared to be more alike than others, we needed to qualitatively assess which codes, i.e., characteristics, were more essential than others and how they connected to each other. Based on a constant comparison analysis, we noticed some patterns. Through a focus on the most typical characteristics, we developed the following five types of contrast problems:

T: Theory focused knowledge development or improvement: M3, B4

These problems are theoretical and dig deeper into existing theories to learn what already exists to improve a situation.

P: Purpose oriented comparison or improvement: M1, B1, B3

These problems describe a clear purpose, either a

Table 1. Overview of types of four shadows of problems, or outside the four shadows of problems, among the 21 Bachelor theses. The letters in brackets denote abbreviations that is used in Fig. 1 and elsewhere in the text. Owing to the large amount (18) of contrast problems, these are further analysed and divided into five categories (Table 2)

Discipline/problem type	**Chemical Engineering and Biotechnology (CE)**	**Building and Construction Engineering (BE)**	**Mechanical Engineering (ME)**	**Mathematics (M)**	**Biology (B)**
Anomaly (A)	0	0	0	0	0
Paradox (X)	0	0	1 (ME 7)	0	0
Contrast	3 (CE 1–3)	3 (BE 1–2, 4)	5 (ME 1–5)	3 (M 1–3)	4 (B 1–4)
Contradiction (C)	0	0	0	0	0
Production flow problem (New category) (F)	0	1 (BE 3)	0	0	0
Domain specific problem (New category) (S)	0	0	1 (ME 6)	0	0

Table 2. Overview of codes among the 18 theses with contrast problems. Alphabetical order of codes. The five letters in capital (T, P, D, I, E) indicate separate types of contrast problems that emerged through the analysis of the theses

Disciplines and thesis number/ Codes	**CE**			**BE**			**ME**					**M**			**B**			
	1	**2**	**3**	**1**	**2**	**4**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**1**	**2**	**3**	**4**
Closed											I			T				
Comparison					I	E						P			P			
Effect/evaluate						E										E		
Explore/identify factors	D								D				D					T
Face future challenges/Future application				I	I									T				
Improvement	D	D	I				I	I	D	D					P	E	P	T
Knowledge gap																E		
Learn knowledge						E								T				
Method preference		D										P						
No preference															P			
Physical product				I	I		I	I		D	I							
Prevention				I	I													
Production maturation			I															
Purpose oriented												P			P		P	
Theory focus														T				T
Tool/method	D	D							D	D		P	D					

comparison of different solutions or an improvement of existing solutions.

D: Development – method based: CE1, CE2, ME3, ME4, M2

These problems deal with the development of chemical, physical, engineering, mathematical *methods* to improve a situation.

I: Improve a present or future physical product or production: CE3, BE1, BE2, ME1, ME2, ME5

These problems improve a physical product, production, or device. Some projects deal with a present situation which could be a product or a current production, others are dealing with issues that are anticipated to improve something for the future. Regardless, the students need to go through similar processes.

E: Evaluate and build knowledge: BE3, B2

These problems evaluate existing knowledge and either deal with improving the students' own lack of theoretical knowledge or address a general lack of knowledge in the research community. Regardless, the students need to go through similar processes.

The naming of the five new types was based on Table 2. The most prominent codes and their connection with others led to the name. E.g., 'purpose oriented' and 'comparison' became 'purpose oriented comparison'. Since 'improvement' in 'purpose oriented' projects also existed, the overall category is 'Purpose oriented comparison or improvement'. The other four categories are formed in the same way.

An analysis of Table 2 revealed that two contrast categories (D, I) were mainly used by engineering students, while two others (P, T) were only used by science and mathematics students. The category (E) went across. This illustrates how PBL is different in engineering versus science and mathematics.

To sum up, from discussing the four shadows of problems in the theoretical framework, we have subsequently identified additional PBL problems, summing up to ten types of PBL problems. The ten problems consist of the four shadows of problems, where the contrast-category was divided into five types of contrast problem. In addition, we found two new types of PBL problems (*production flow* & *domain specific*), which were not part of the four shadows of problems framework, see Table 1.

6. Discussion

6.1 When Theses did not apply PBL Terminology

Several of the theses did not contain a problem formulation or used the term problem. Instead, many wrote "aims", "research question" etc. Shared goals in a project [26], also called aims, are not identical to an identified problem and knowledge gab which constitutes the problem formulation [18]. In these cases, we decided to not dismiss the thesis as PBL but we "looked behind" to find the essence – the actual problem. Another issue is the occurrence of problem formulations that were yes/no questions. Usually, problem formulations are advised against being formulated as a yes/no question, here we again "looked behind" to find the essence. For a PBL university, and given that these are the Bachelor theses, it warrants some critique that the students do not all apply PBL terminology, when they in fact do PBL. An explanation might be that the students already have begun using the terminology of their profession, and therefore they have "abandoned" the PBL terminology that they have previously learnt, and likely applied at earlier semesters.

6.2 Great Variation of Problems

We saw great variety in origins of the problems. The problems of two theses (ME1, ME7) came from companies. One might discuss to what extent a thesis originating in a company or in a supervisor's research project (ME5) is true PBL since the students may not have much to say in determining the problem. On the other hand, such problems are clearly exemplary and an overall problem from a company is very often an *initiating* problem for the thesis. Afterwards, the students decide what to include in the problem analysis and formulate a specific problem they wish to solve. In fact, the students in these situations defined the problems themselves. That the students take ownership of the problem, was also documented by Nørgaard et al. [27]. Here, the students, on their own initiative, even moved beyond the outlined semester project guidance for the business area to be selected to identify another type of company and subsequently specify its challenge. . These are examples of the necessary elasticity of PBL – and the principle of exemplarity is essential.

Concerning the four shadows of problem types (anomaly, paradox, contrast, and contradiction), most (18 of 21) theses involved contrast problems, and we further developed these 18 into five types of contrast problems. We also identified two additional categories (*production flow* & *domain specific*). Although we find that these types of problems are different, there is also a continuum. In fact, all 18 contrast problems were different, but common for most of them is the challenge to improve, to find better solutions, to design or optimize products and methods.

6.3 How our 10 Types of Problems Relate to the Framework of Jonassen and Hung

Jonassen and Hung describe another framework where the domain of PBL-problems is structured as a two-dimensional coordinate system with well-structure versus ill-structured on one axis and complex versus simple on the other axis. They hypothesize that "the problems that are likely to be most successfully implemented in PBL programs are those that are moderately ill-structured . . . and slightly above average in complexity" [8, p. 25]. We find this framework to be very relevant and we therefore applied it in a deductive analysis to the ten identified PBL problems (Fig. 1). We argue that problems which are either *anomaly* (A), *paradox* (X), or *contraction* (C) are all ill-structured and complex; however, a contradiction might be even more ill-structured than an anomaly. A *production flow problem* (F) is typically relatively structured as the students learn to apply certain procedures, but its complexity varies. A *domain specific problem* (S) can be quite complex depending on the problem, but is also relatively structured as this is in a rather fixed domain. In relation to our five types of *contrast problems*, the *theory focused knowledge development or improvement* (T) can be rather complex but are likely also relatively structured as the student dig deeper into existing theories. A *purpose oriented comparison or improvement* (P) is well-structured as it has a clear purpose from the outset, and also less complex as it deals with existing solutions. The *method-based development* (D) focuses on development of methods which are structured problem with different degree of complexity. Problems which are concerned with *improving a present or future physical product or productions* (I) may be ill-structured as they various investigations and they can have different degrees of complexity. Finally, problems that are concerned with *evaluating and building knowledge* (E) can be both ill-structured and complex. Fig. 1 illustrates how the ten problems can be placed on the scales of Jonassen and Huang.

6.4 Do all the Identified Problems enable PBL?

The placement of each of the ten types of problems is *approximate* within each quadrant. However, it

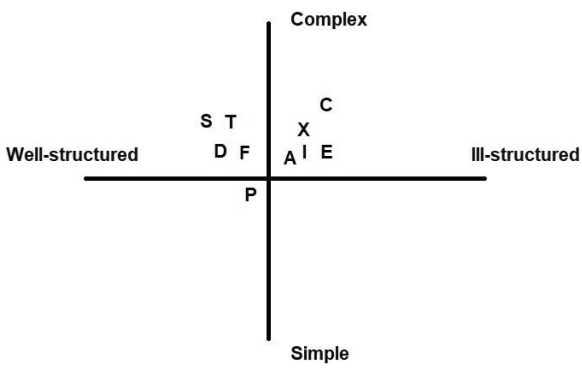

Fig. 1. Overview of the ten types of problems discussed in the paper and approximately how they are situated in relation to each other, inspired from [8, p. 25]. To recapitulate: The ten problems consist of the four shadows of problems, where one, contrast, was divided into five, as well as two new types defined.

leaves us with the questions if all types of problems are "PBL". Five (A, C, E, I, X) are various degrees of being complex and ill-structured, the hallmarks of PBL-problems whereas the five others (D, F, P, S, T) are rather well-structured, with P also being less complex. ME6 is the "D-problem" and as we stated above bears resembles to a task. Above we also describe task-projects as not being PBL. So, are the five problems (D, F, P, S, T) PBL or not? We wish to argue that being ill-structured is not the only characteristics of a PBL problem. As also Jonassen and Hung [8, p. 25] argue, being "authentic, that is, contextualized as to students' future or potential workplaces" is a central characteristic for a PBL problem. All these problems are clearly authentic/exemplary and include a large degree of freedom for students to make decisions. P, however, might be less complex, in comparison. We wish to argue that these ten problem-types are all PBL, but to a varying degree with A/C/E/I/X being more "pure PBL" and D/F/P/S/T less, with P as even less. We believe that all serve a purpose as part of a PBL curricula and if students are exposed to a variety of problem-types, they will develop into being very competent problem-solvers in engineering, science, and mathematics.

6.5 Limitations

A limitation of our analysis is that we did not in detail research the connection between each project and the corresponding curriculum. Such an analysis might reveal if particular types of problems are required, or if the description of PBL is general enough to in fact encompass all the ten types of problems. Some problem types might be more common or natural to specific engineering, science, or mathematics disciplines. Another question that could be interesting is to study if the curricula perhaps stipulate mainly contrast problems, as this was clearly the most common type of problem. Nevertheless, we studied the curricula to the extent that it was clear that they all required PBL, and the focus for this paper has been the nature of the problems.

Another limitation of the study is that not all engineering, science, and mathematics programmes were analysed and only one year of Bachelor theses. A further study might result in even more types of problems and might show some more tendencies about which types of problems are typical of a profession. Interviewing students and supervisors might reveal why for instance PBL terminology was not being used and might also reveal previous versions of the problem formulations. This was in practice not possible owing to the time span of several years since the theses where submitted. Regardless, the main contribution of our work is an extension of an existing framework for problems, which can be inspirational.

7. Conclusion

This study was done at AAU, but we wish to argue that if students get experience working with a variety of problem types, the students acquire more PBL skills and competencies, and the students also get more knowledge about the types of problems that actually exists within their fields. Only meeting a limited type of problems, might not prepare the students fully to the profession. When applying PBL world-wide in university engineering, science, and mathematics curricula, our extended framework with ten types of PBL problems give inspiration to the organisation of these programmes as well as ideas on how to organise project work, not just at AAU. Also, the framework of Jonassen and Hung gives an easier and more accessible overview of essential scales of PBL which we believe can be applied across disciplines. The level of details of the ten problems described here, could be useful inspiration for more specific planning of PBL as it exemplifies different interpretation of PBL. We believe that both students and supervisors would benefit from knowing about the existence of this framework to provide ideas for student work. In order for this to happen, both students, supervisors, and curriculum planners need to become familiar with this framework in order to create ideas for possible new venues for students to work on. Assistant professors at AAU have mandatory introduction to PBL and the results of this study could become part of such introduction as well as on e.g., department teaching workshops etc. The framework is developed based on an analysis of AAU Bachelor theses, but giving that the disciplines of engineering, science, and mathematics are international, we assume that the framework would be relevant also outside of AAU.

As described in the introduction, a system approach argues that the education parts cannot be seen in isolation. This holds true also for PBL. The way any institution implements PBL, including how 'problems' are interpreted, affects and is affected by other parts of the organization. For that reason, 'problems' might naturally differ in different institutions – and different educational and professional settings. PBL is not a fixed model, but *principles*. However, the suggested types of 'problems' described in this paper might affect the application of PBL in higher education institutions in the future, and by being transferred to other institutional settings, it is likely that some might be revised.

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