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Variation in PBL in different university STEM study programmes: How elastic is PBL?

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Abstract

Aalborg University (AAU) in Denmark practises problem-based learning (PBL) in all study programmes in all faculties. The PBL principles are broadly defined; different study programmes may choose a variety of PBL practices. The purpose of this paper is therefore to analyse how PBL student projects look in a selection of different STEM study programmes and to discuss the elasticity of the PBL principles. One would expect PBL to "look different" when comparing, for instance, projects in the humanities with science, but we want to learn if there is any variation *within* the STEM subjects. We analysed groups of three, four, and seven recent student Bachelor reports (6th semester) from Mathematics, Biology, and Mechanical Engineering, respectively. The subjects are taught and recognised worldwide. We focus on Bachelor reports since they show how students work with their subject by the end of a PBL education. We expect that by choosing the final projects, we avoid "beginner-issues" in PBL as the Bachelor project is the seventh PBL project the students do at AAU so any variation in the projects is not due to students not yet grasping the principles of PBL. The research methodology is documentary analysis of curricula and the reports. The focus is on how the reports describe and analyse their problem and what types of problem the students work with. Our findings show a great variation within problems but mainly the students worked with contrast problems, thus here there is room for even more diversity of projects and elasticity of PBL. Some reports did not apply PBL terminology but instead wrote, for instance, aim. Most projects were discipline projects while two were a kind of multi projects where groups collaborated with another group in different ways. Overall, we saw a great variety of PBL, which testifies to the elastic nature of PBL.

Keywords: STEM education, problem-based, problem variation, project work, Bachelor

Type of contribution: PBL research paper

1. Problem-based learning at Aalborg University

Aalborg University (AAU) in Denmark has, since it was established in 1974, organised all curricula around the principles of problem-based learning (PBL). The PBL practice at AAU has undergone several changes (Dahl et al. 2016; Kolmos et al. 2013), but the PBL *principles* have not changed substantially. The most recent formulation (Askehave et al. 2015) states six PBL principles: (1) the problem as point of departure, (2) projects organised in groups, (3) projects supported by courses, (4) collaboration with a supervisor who acts as a facilitator, external partners and other groups, (5) exemplarity (the project's learning outcomes can be transferred to similar problems relevant to the student's future profession), and (6) student responsibility for learning. The students work in groups with projects where theory is applied to solve or explain either a practical or a theoretical problem. The problem formulation is developed through a problem analysis of an initiating ill-defined problem chosen within a prescribed semester theme. This problem formulation becomes the guide for the project. The project usually accounts for 15 ECTS while the other half of the semester consists of courses that support the project. A PBL introductory course is taught in the first semester to aid the students' work in PBL (Kolmos et al. 2004). Although AAU has shared PBL principles, PBL is exercised with variation across the faculties and the departments. Since AAU does not have a PBL *model*, but PBL *principles*, this allows for flexibility. 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 whether too much "freedom" stretches the PBL to an "anything goes" situation. Therefore, in this paper, we study how PBL is framed in different programmes by analysing the types of problems we see in the student reports and discuss to what extent they reflect the PBL principles.

2. Theoretical approach

2.1 What types of problems do students work with?

Dahl (2018) argues that mathematical problems arise in three different contexts: daily context, professional practical context or in the context of the research society. Problems in all three contexts might be practical or theoretical. In engineering, PBL mostly originates in practical problems concerning issues such as transport, health and sustainability. According to Adolphsen (1997), a practical problem becomes theoretical when it asks 'why' the practical problem has happened, and theoretical problems often arise from the contradictions that one experiences in the confrontation with practical problems. Adolphsen (1997, p. 32-33) further elaborates that a practical problem is a contradiction between what you want and what you can do, and it has the same ontological status as an action. A theoretical problem is an incomprehension, you know what you have, and it has the same ontological status as knowledge. Engineers, however, 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 on scientific laws, which creates a connection to science. In science, a problem could be a knowledge problem that initiates the learning process, for instance, a description of a natural phenomenon, and the student group should then find or provide an explanation of that phenomenon that satisfies the scientific criteria of the specific subject (De Graaff 2016). In this study, part of the analysis of the projects' problems evaluates to which extent they are theoretical or practical.

However, to get deeper into characterising the problems, we apply the "four shadows of problems" (Holgaard et al. 2017, p. 1072) which are: *anomaly*, *paradox*, *contrast* and *contradiction*. In Qvist's (2004) work, the author describes an anomaly as an exception from the rules/norms that "appears in a way, which differs from what we had expected" (p. 81) and suit projects concerned with unexpected or surprising observations. A paradox is "two sets of facts meeting in contrast" (Holgaard et al. 2017, p. 1072), or an "anomaly that also problematises existing perceptions/theories" (Olsen & Pedersen 2019, 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" (Holgaard et al. 2017, p. 1072), or as stated by Qvist (2004, p. 89): "between a situation of status quo and a possible other situation - a vision". This could be seen in optimisation projects. A contradiction is "a simultaneous statement or relation which mutually excludes each other" (Holgaard et al. 2017, p. 1072). Thus, it is stronger than an anomaly, for instance, condition *a* excludes condition *b*, and vice versa. Holgaard et al. (2017) argue that these abstract problem definitions can be difficult to recognise in practice. We, however, find that the level of detail in those descriptions help characterise the types of problems the students work with, and thus provide a more precise overview of how PBL looks.

2.2 What kind of projects do students work with?

De Graaff and Kolmos (2003) distinguish between three types of projects: task projects, discipline projects and problem projects. In *task projects*, there is a very high level of planning and direction from the supervisor and the problem and the methods are chosen in advance. The students have very little opportunity to make changes to the problem or methods. Such projects are incompatible with PBL principles. However, even if task projects exist at AAU, an analysis of the project reports alone would most likely not reveal this, as reports typically do not contain anything about the process and who made which decisions. The *discipline project* also has a rather high degree of direction from the supervisor as the discipline and methods are chosen in advance, but the groups are allowed to identify and define the problem within guidelines and frames, e.g. a semester theme. These projects are PBL projects since the students have some determination in choosing the problem, which then becomes the point of departure. The *problem project* is when the problem is decided by the students' own initiative and completely directs the choice of both discipline(s) and methods. A problem project can be interdisciplinary. One might discuss if problem projects are "more PBL" than discipline projects. We would agree, but this is an example of the elastic nature of PBL. A criterion in determining whether a project is PBL is to what extent the problem directs the project and if the students have some determination in choosing the problem.

A more recent (Holgaard et al. 2019) way to conceptualise different types of projects at AAU includes the idea of students collaborating not only within a group but also with other groups, see Figure 1:

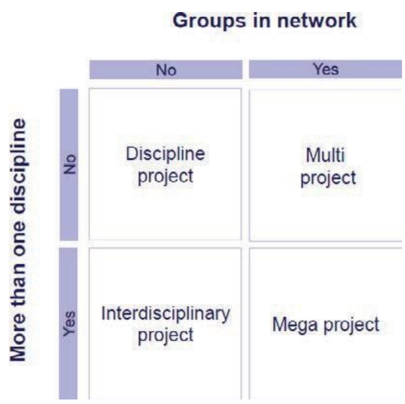

Figure 1: Overview of four types of projects (figure translated from Holgaard et al. 2019)

Discipline projects have the purpose of socialising students into a discipline and deal with well-defined problem fields. In multi projects, students collaborate across teams but within a discipline. Interdisciplinary project groups consist of students from different disciplines. A minor version could be groups including other disciplines as part of their work. They work with an open but rather narrow problem area. Finally, in mega projects, groups work with open and complex problems together with student groups from other disciplines. There is no contradiction between the two ways of conceptualising the types of projects. The types mentioned by Holgaard et al. (2019) do not directly mention problem projects, but it is possible for all four types to be problem projects. The discipline project, however, is the only one of these four types that is a "discipline project" in the sense of De Graaff and Kolmos (2003).

3. The research methodology

We use document analysis as a qualitative research method to analyse the curricula and the students' Bachelor reports. We accessed the curricula either online on the university website or by contacting study secretaries in cases of older curricula. The reports are electronic material since all submitted student reports at AAU can be found on an internal database accessible to all staff. Bowen (2009) noted that "document analysis requires that data be examined and interpreted in order to elicit meaning, gain understanding, and develop empirical knowledge" (p. 27). Unlike other research methods, the main characteristic is a lack of researcher intervention in the documents to be analysed (Bowen 2009). Therefore, it is our own interpretation that needs critical reflection.

We analysed groups of three, four, and seven recent Bachelor reports (6th semester) from Mathematics, Biology, and Mechanical Engineering, respectively. The subjects each represent a central STEM area. We focus on Bachelor reports as they show how students work with their subject by the end of a PBL education. We reviewed the last five years to find a year in which there were at least three Bachelor projects submitted in all three education programmes. This relative high number of projects makes it possible to see some span of projects. We wanted reports from the same year as students would then have had the same kind of PBL introduction the first semester. We chose 2017 and analysed all projectreports.

4. Analysis

All projects are, in principle, group based, but we found examples of a student working alone. The projects are all 15 ECTS. Whenever titles are not in English, we have provided a translation. Table 1 (see after references) presents an overview of the analysis. Here, the letters A, P, Ct, and Cn represent anomaly, paradox, contrast and contradiction, respectively (Holgaard et al. 2017).

4.1 Mathematics

The curriculum (Faculty of Engineering and Science 2010) mentions PBL in the general competence profile for the whole education. For instance, this is done in the skill learning goal about becoming able to apply skills connected with working with problems within mathematics. Another PBL skill learning goal is concerned with being able to communicate scientific problems and solutions to peers, non-specialists or collaborating partners and users. In relation to the Bachelor thesis, the curriculum states that the students should have a large amount of freedom in choosing the subject. The skill learning goals for the Bachelor project, in line with the general competence profile, states that the students are supposed to become able to assess theoretical and practical problems within the subject as well as communicating problems and solution models within the subject to both peers and non-specialists. Thus, PBL and being able to work with both theoretical and practical problems is clearly a central part of the curriculum. These are formulated as part of the skill learning goals. In 2017, three Bachelor projects were submitted.

Project 1. Title: "Analysing Wind Power Time Series Using ARIMA Models" (5 students, 95-page report). In the introduction, the report began by arguing "global warming is an increasing problem in the world". This leads to a discussion of "the application of renewable energy such as wind energy". It also explains that it is impossible to stock wind energy. 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". This project clearly originates in a real problem (global warming) as initiating problem; however, although the "problem" they work with is clear, it is not formulated as an (initiating) problem but as an "aim". This project thus works with a contrast problem as they envision a better solution than the present.

Project 2. Title: "Time series and forecasting wind power" (5 students, 85-page report). This project is quite similar to Project 1. As in Project 1, the introduction discusses the issue of finding alternative energy sources. However, the report deviates from Project 1's report as it has separate sections termed "problem analysis", "thesis statement", and "project delimitation". All terms that are highly influenced by PBL pedagogy. The content of the problem analysis is, however, quite similar to what was written in the introduction to Project 1, both leading to an introduction of the time series analysis of data gathered over time. The section called 'thesis statement', consists of what in PBL is usually termed the problem statement and sounds: "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 wording is in fact a problem statement. The delimitation section described, more specifically, which types of time series analysis is used and which are not. This project is clearly termed in PBL language, and as above, presents a contrast problem. Both Project 1 and 2 are practical problems.

Project 3. Title: "Robotics Arms - An Application of Gröbner Bases" (3 students, 61-page report). This project examines the so-called forward and inverse kinematic problem for robotic arms in two and three dimensions. In the introduction, the report begins by discussing 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 then explains the forward kinematic problem as "if a certain set of angles are given then where is the hand placed?" The inverse kinematic problem is "what should the angles be if we want the hand to be in a certain position?" 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 actual report is a theoretical report, working with two dimensions as no real robot only works in two dimensions. However, in the report, the group also sometimes looked at three dimensions, but the overall impression is a theoretical report. Although the kinematic problems are termed "problems", the group does not specifically term something a problem statement. It appears that the reference to industry is not the driving force of the project as it is just mentioned one time, line 1 in the introduction of the report, which does not actually justify a practical side as the driving force for the project. The problem is mainly a contrast problem as it deals with explaining how to better control robots.

4.2 Biology

In the competence profile, the curriculum (Faculty of Engineering and Science 2014a) states that the students should gain skills to identify, analyse, interpret, assess and communicate complex problems within biology. Specifically for the Bachelor project, two types of projects are possible depending on whether the students are one-subject students (§3.13.5) or have another subject (*sidefag*) in humanities, social science or natural science (§3.13.6). The learning goals in §3.13.5 do not mention 'problems', but the theme is specified as Aquatic biology. In §3.13.6, however, as part of the description of content, the project should originate in a problem within a defined area within the main parts of the education (there is no specific theme). Furthermore, the competence learning goals state that the student should be able to independently organise and complete a project. Thus, a part of the purpose of the Bachelor projects, and the education as a whole, is to make students work in a problem-based way. In spring 2017, four Bachelor projects were submitted. It was not clear from the projects which of the two types of Bachelor projects they were. They were all in Aquatic biology, thus the project was initiated by practice.

Project 1. Title: "The influences of land use on water quality over different spatial scales – buffer zone versus catchment: A review" (3 students, 27-page report). 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 were compared. The report does not explicitly state a problem; however, it is easy to determine that the problem they worked with is how to secure healthier water quality. This appears to be a contrast problem as research does not yet know the answer, but the Bachelor report reveals that different studies have different conclusions.

Project 2. Title: "The effect of macrophytes on nitrate removal in aquatic microcosms" (4 students, 14-page article). The aim of the project is "to evaluate the effect of macrophytes on nitrate removal in aquatic microcosms". Moreover, the article writes: "However, studies accounting for the effect of macrophytes on nitrogen removal and denitrification are lacking". As above, the students do not mention the term "problem"; however, we still 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.

Project 3. Title: "Nutrient deposition from colonies of cormorants: A case study from Tofte Lake" (3 students, 48-page report). The group describes the purpose of the project to investigate if a colony of cormorants contribute to the nutrient deposition in a lake: "This is due to the large amount of phosphorous and nitrogen in their droppings deposited to the soil and water in the area of colony". This may have an effect on the water quality, and it is therefore relevant for the implementation of the EU Water Directive. 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. This is therefore to some degree a multi project. This group also does not specifically state a "problem". Instead, they list three hypotheses they wish to test. The problem is easily discernable as threats to water quality. As above, the problem is a contrast problem.

Project 4. Title: "Eelgrass in the Limfjord [fiord]: growth and sediment" (1 student, 19-page report). This project 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. The project wants to illuminate which factors that affect the spread of eelgrass. This project uses the term "problem" to describe the purpose of the project. As above, the problem is a contrast problem.

4.3 Mechanical engineering

In the competence profile, the curriculum (Faculty of Engineering and Science 2014b) states that the students should gain skills to use modern methods and tools to describe and solve problems on a scientific basis in mechanical engineering and production (manufacturing). Additional competences are obtained through the Bachelor project and includes that the students must be able to indicate how a relatively complicated product is specified, constructed, managed and produced, and to document this professionally. During the project, the students have to gain the skill of becoming able to design a mechanical system based on a *well-defined problem*, which must meet a number of requirements in terms of price, low weight, dynamic performance, control and regulation, material and process selection. As an overall competence, they have to involve at least two significant engineering disciplines and explain how these disciplines respectively affect and depend on each other. In spring 2017, seven Bachelor projects were submitted.

Project 1. Title: "Baseplate with adjustable stiffness" (4 students, 76-page report). The problem is introduced by Grundfos, a pump producing company. It discusses when customers install the industrial pumps and the foundation does not meet the recommendations from Grundfos. An unfavourable foundation can result in noise "from the vibrations from the pump and motor going through the baseplate and further transfer energy to the foundation". The initial problem formulation was: 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 ended up with the following problem formulation: 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. Title: "Design of a movable theater lamp" (1 student, 55-page report). A system of automated movement of a theatrical lamp is investigated in the project. The thesis is based on a case from a local music venue, where there is 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. The problem formulation is: "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 results of the problem analyses were to establish technical criteria for the dimensioning of construction and motors so that it can be applied to a local venue. As above, the problem is a contrast problem.

Project 3. Title: "Design and Modelling of Planar 3-DoF Robot" (4 students, 175-page report). The aim of this project is to improve a three degrees-of-freedom system, a task the group was given by their supervisor. The focus of this report was analysing a 3-DoF system by using a CAD model and finding possible improvements for the current system. The problem formulation is: 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. Title: "Design of Active Rear Wing for Formula Student Race Car" (3 students, 149-page report). There is no stated problem but *a wish to improve* an existing formula student race car from AAU. They sought to improve the car by designing a rear wing. The wish to design a versatile product was stated based on the following two active functions defined: (1) reduce drag to decrease air resistance and (2) improve braking to increase braking performance. As a reason for employing a rear wing, or aerodynamic elements in general, the need to increase the force acting on the wheels by pushing the car down is mentioned. The rear wing, which is to be designed, must comply with relevant rules and regulations. The project 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. Again, this is a contrast problem.

Project 5. Title: "Development of Laser scanning system & Study of Laser Bonding" (4 students, 93- page report). The project is part of the laser processing research in the Department of Mechanical and Manufacturing Engineering at AAU, dealing with the development of a system of high-speed laser processes. This project has been worked on before, and two previous groups in previous years have designed a laser booth and procured the necessary equipment. This group wants to finish the work. The project 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. However, the project is different from the others because it builds on two other student projects. We could argue that it is part of a multi project.

Project 6. Title: "Energy consumption of 2 DOF robotic arm - Set up analysis tool" (4 students, 136- page report). In the report, the students mention the relevance of streamlining industrial robots that are entering Denmark. The aim of the project is to develop an analysis tool through which the influence of specified parameters on the energy required to power a two DOF planar robot arm can be studied. The investigated parameters with an influence on the required energy of the motors, are defined as follows: link length, outer radius of the two links, factor of safety (FOS) and the trajectory. The investigation has its starting point in a case, which states that the robot arm must be able to transport an object with a mass of 5 kg. The said object must be moved between two predefined coordinates; from (0,4 m : 0,2 m) to (0,8 m: 0,7 m) in a matter of three seconds. The following problem statement is: How can an analysis tool be developed in order to determine the lowest energy consumption of the motors, searching among the combinations generated when combining ranges of investigated design parameters? It is a contrast problem.

Project 7. "Corrosion of helix tubes" (4 students, 92-page report). The starting point is a problem posed by the company Alfa Laval, which deals with corrosion of helix pipes in OC-TCi boilers. The OC-TCi boilers contain both straight tubes and helix tubes where the helix pipes corrode significantly more strongly than the proper pipes despite being located in the same boiler water. This leads to the project's initiating problem: what causes the helix embossed pipes to corrode before the proper (right) pipes? After the problem analyses, the group stated the problem that the helix pipes corrode more than the right pipes, despite measures aimed at reducing corrosion in general. In analysing the initiating problem, the types of corrosion, stress corrosion and strain corrosion (SICC), pitting and crack growth were found to be relevant to the OC-TCi. This leads to the main question of the project: 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 project differs from the others. We face a paradox. Two different pipes corrode at various speeds, despite being located in the same boiler water.

5. Discussion and conclusion

We sometimes saw that the projects do not use the term problem even though a problem was easy to identify. We did not have the opportunity to interview the students about this, which might have provided interesting background. However, for a PBL university, it seems odd to not apply PBL terminology such as "problem". Why did students not use this terminology? One answer might be that the students are so used to thinking in problems, that they no longer see the need to use the specific terminology. Another explanation could be the question of why the specific term "problem" is so important if it is otherwise clear what the project is about? The students might not be clear about the terms research question, thesis statement and problem formulation and perceive them as synonymous.

We noticed a wide range in the length of the Bachelor projects (14–175 pages) as well as in the number of students working together (1–6). It is worth noting that for Mechanical Engineering, there is a requirement of a maximum of four students in the group (Faculty of Engineering and Science 2014b). One Biology report was an article. It is a sign of the elastic nature of PBL to see Bachelor projects of such variety. Furthermore, even though some reports were clearly shorter than others, this does not mean less work was involved as the collection and analysis of samples in a laboratory is a time-consuming part of a project. It appears a bit odd that the average number of pages per student is very varied: 3–55 pages. However, discipline traditions of how long a "good project looks" may also have an impact, which we were not able to study in this paper. The curricula all described PBL as a basis for the Bachelor projects. We, however, did see some differences in some of the details. For instance, in biology, PBL was included mainly as part of the competence goals, whereas for mathematics and mechanical engineering, it was part of the skillgoals.

We also saw great variety in origins of the problems. Some were clearly external, for instance coming from companies, while others were not. One might argue to what extent a project originating from a company or a supervisor's research project is true PBL since the students may not have much say in determining the problem. On the other hand, such problems are clearly exemplary. Here you can argue that a problem from a company is very often an initiating problem. Afterwards, the students must decide what to include in the problem analyses to state the problem they wish to solve. In fact, the students in this situation define the problems themselves, which supports the finding from Nørgaard et al. (2017). Hence, they have taken ownership of the problem. In any case, this is an example of the necessary elastic element of PBL at AAU — and also why we need the fifth principle of exemplarity.

As illustrated in Table 1, most projects were discipline projects, but on two occasions, we found projects that had a resemblance to multi projects. In the project where the group continued the work of previous groups, the initiating problem did not come from the students themselves, but they bought in/took ownership of an existing problem and continued the work. This might also be an example of the exemplary and elastic nature of PBL. We saw that most projects were initiated by practical challenges. Sometimes (MA3) a practical initiating problem appears to have the started project, but when reading the whole report, it appeared to only have had a very minor role.

Finally, concerning the four problem types, anomaly, paradox, contrast and contradiction, as seen in Table 1, most projects were about contrast problems, but these were quite different. Further study into the nature of problems would need to see if this category could be divided into sub-categories. We did wonder why we did not see many other problems. Here, it appears that PBL at AAU might be less elastic than it should be. More variety in problem types would still be PBL but might teach the students even more PBL skills and competencies.

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Education	Problem Type								Project Type			
	Purely theoretic				Initiated by practice				Disciplinary	Inter-disciplinary	Multi	Mega
	A	P	Ct	Cn	A	P	Ct	Cn				
MA 1							X		X			
MA 2							X		X			
MA 3			X						X			
BIO 1							X		X			
BIO 2							X		X			
BIO 3							X		X			
BIO 4							X		(X)		(X)	
Mech 1							X		X			
Mech 2							X		X			
Mech 3							X		X			
Mech 4							X		X			
Mech 5							X				X	
Mech 6							X		X			
Mech 7						X			X			

Table 1: Overview of analysis