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Problem-Oriented Teaching and Learning at Roskilde University

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Abstract

Drawing on a historical account of the development of problem-oriented project studies at Roskilde University (Denmark), this article analyses the key concepts underpinning this educational tradition as well as the positions and frameworks advanced by its proponents. Focusing on problems and how they originate in such studies, it distinguishes between problems of practice, which concern challenges that arise in areas of practice and require resolution, and intellectual problems, which arise from efforts to understand phenomena and processes through scientific or scholarly inquiry. The problem-oriented tradition at Roskilde University has tended to privilege problems of practice, while neglecting intellectual problems. We argue that this is a highly problematic tendency because intellectual problems have significant formative value for learners. Hence, we advocate for a more pluralistic understanding of what constitutes a legitimate problem in project work. The argument is illustrated through authentic examples of discipline-related intellectual problems from science and mathematics education at Roskilde University.

Keywords: Problem-orientation; problem types; discipline-related intellectual problems; Roskilde University

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Introduction

Taking its point of departure in a historical account of the development of problem-oriented project studies at Roskilde University (Denmark), this article aims at providing an analysis of the key concepts of this notion as well as of the different positions and frameworks promoted by protagonists in this development. Furthermore, we plead for adopting a pluralistic view of the kinds of problems that deserve "civil rights" in project-oriented project work.
In September 1972 Roskilde University Centre (RUC) opened its doors for its very first cohort of students. As a marked example of "paving the road while driving on it", only two-year so-called *basic education programmes* were in place when the students arrived. Three such programmes were established, in the humanities, in the natural sciences, and in the social sciences. MAN (Mogens Allan Niss) was a member of the founding staff for (the natural) science programme(s) from the very beginning, as well as for the subsequent mathematics programme. MN (Martin Niss) led the bachelor's programme in science from 2020-2027, and before that the physics programme 2014-2019.

It was part of the initial planning scheme that a number of three-year further education programmes were to be designed and implemented during the first two years such that the students could move on to 3 (or 1½) year studies right after having completed one of the basic programmes. This would result in degree programmes of a total of either 5 (master level) or 3½ (a kind of bachelor level) years. This was the reason why the institution was named "university centre" rather than just "university", since the term "university" was reserved for institutions that offered only master's and PhD-level programmes, even though RUC was a research institution from the very beginning. In 2008, it changed its name to Roskilde University in order to better reflect its actual status. As the acronym RUC had been an established "trademark", well known to the public, for 36 years, it was decided to keep this acronym, although the literal referent of "C" no longer existed. It should be mentioned that in 1999 all Danish universities were subjected to the so-called Bologna model, which instigated a sequential 3 (bachelor)/+2 = 5 (master)/+3 = 8 (PhD) system as the standard structure. This implied that RUC no longer would have its own special structure. So, keeping "Centre" in its name would simply be misleading.

One trait was common to all three basic programmes. They were all centred around *problem-oriented project work* carried out by small groups of students. In the humanities and social science programmes such work was in fact the only study activity on the agenda during the first handful of years. In contrast, the natural science programme included an even split of 50% project work and 50% course work already from the start. Although typically innovative in content

and form, the courses were designed, led, carried out, and assessed by the academic staff, as was – and is – usual.

As problem-oriented project (group) work formed the centrepiece of the three programmes, we need to pay closer attention to what this is. The concept is an amalgam of three rather different, in fact conceptually independent, kinds of components. As the name suggests, project work is a particular *way of working*, whereas problem-orientation is a *content category* focusing on the investigation of a (set of) problem(s). *Project work* – the first component – is undertaken in order to obtain some kind of product meant to fulfil certain goals or requirements. It can be conducted by a single person or by a group – the second component – of individuals, in university contexts consisting of students supervised by an academic staff/faculty member. At RUC, in the early years and in most subsequent periods, groups typically were small *project groups* composed of 3-7 students. Project groups are meant to carry out and take full responsibility for all the decisions, actions, and activities involved in undertaking the project work within the overall framework laid down in study programmes and regulations (see, e.g., Blomhøj & Kjeldsen (2008) and Niss (M.) (2025)). Dependent on its purpose, a piece of project work can generally be of a very diverse nature and have a highly diverse kind of content. In *problem-oriented* project work, however, the key purpose is to deal with a problem, or a set of problems, with the ultimate goal of "solving" it (or them). Hence, the content of the project work in this case consists of everything involved in dealing with the problem(s) towards achieving the goal.

Project work can deal with lots of things other than problems. For example, it can focus on training participants to effectively perform certain tasks or procedures. And, depending on their nature, problems can be investigated and solved in several other ways than by means of project group work, e.g. by seeking extant answers or solutions in relevant literature. Hence, the content component and the way-of-working component are indeed different and independent.

Problem-oriented project work (POPW) and problem-based learning

The key term in problem-oriented project work (POPW) is "problem", which is also the key term in what has become known as "problem-based learning" (PBL). Hence, an in-depth compare-and-contrast analysis of POPW and PBL must have an investigation of the very concept of problem as a core ingredient. Below we shall offer a first attempt at such an analysis.

Before doing so, however, it is worthwhile to attend to the issue of why POPW, respectively PBL, were introduced into tertiary education in the first place. POPW was first introduced in the late 60's and early 70's at some German, British and Danish universities and colleges (Cornwall & Schmithals, 1977) for a variety of different reasons. One such reason (Andersen & Kjeldsen, 2015a) was to bridge the gap between tertiary academic education and the post-college professional world of work - a gap which was sometimes named the "practice shock" - by preparing students for types of work characteristic of different sorts of academic workplaces. Another reason was to have students experience some degree of "authenticity and relevance for learning" of their studies, as regards both the objects and the subjects of study and the ways these objects and subjects could be treated in investigative processes (Andersen & Kjeldsen, 2015a, Habbal et al. 2024). A third reason was that by letting students take responsibility for their own work, they would experience motivation, ownership, and agency in their studies rather than being passive recipients of top-down knowledge transmission (Illeris 1974). A fourth reason (Simonsen & Ulriksen, 1999, Ulriksen, 1997, Christensen, 2007) was to place students in situations that required long-term collaborative work with peers and thus expose them to and prepare them for the challenges and intricacies of such work and to the different roles it calls for.

As is well known, tertiary academic education takes a multitude of different forms and purposes. Some are devoted to the study of scientific and scholarly academic disciplines and subjects in their own right – e.g. mathematics, physics, social science, economics, philosophy, linguistics, history, or geography, to name just a few. Others are studies that prepare for well-defined professions, such as, for example, medical doctor, engineer, teacher, lawyer, pharmacists, or architect. Especially with the latter sort of studies, students often experienced a gap between, on one the hand, the foundation subjects and, on the other hand, the professions-oriented subjects included in their study programmes. In some cases, the gap between these two kinds of subjects was seen, by students, as so large that the foundation subjects appeared to be irrelevant, without any obvious bearing on the "real" (i.e., profession-oriented) material that initially recruited the students to the programmes. Hence, this gap might end up rendering the studies demotivating for some students. PBL was introduced, above all, in order to counteract the consequences of this gap. To some – but a much minor – extent this was also the case with POPW.

Above, we mentioned "foundation subjects". We should also mention "service subjects". Foundation and service subjects are included in a study programme in order to provide a conceptual, theoretical and methodological foundation for the essential parts of the programme, like, e.g., mathematics for physics studies or engineering programmes, chemistry for medical studies, and statistics for

social studies and economics. Service subjects may also be meant to facilitate dealing with these essential parts of a programme, like foreign languages – say Latin - for programmes in history, literature or philosophy. Thus, foundation or service subjects are secondary subjects in relation to the primary subjects that constitute the core of a study programme. This does certainly not imply that foundation or service subjects are unimportant, quite the contrary. For example, one cannot study physics, engineering, actuarial science or economics without being well versed in mathematics, or study medicine or pharmacy without a strong background in chemistry. Despite their importance, foundation and service subjects may often be felt by students as a detour from the route of essence. One of the reasons for proposing POPW or PBL as an educational framework for academic studies was – and is – to create a platform that allows for a demonstration of the role and importance of foundation and service subjects for the study of this essence.

What is a "problem" and how do problems originate?

The term "problem" has several different meanings, and problems come in a multitude of different sorts, shapes and forms, and have a variety of different origins. Basically, a problem is a phenomenon, condition, process or issue that is "nagging", "hurting", "biting", or "itching" in one way or the other and hence provides a *challenge* for individuals, groups, communities or societies. Any problem can be stated in terms of a set of interrelated questions: What is the problematic entity we're talking about? Why is it a problem? To whom is it a problem? What does it mean to handle, or eventually solve, the problem? And how can the problem be dealt with so as to achieve a satisfactory outcome?

There is neither an end to what may constitute a problem, nor to whom a problem is a problem. In academia, there are fundamentally two classes of problems. *Intellectual problems* are problems where there is something which somebody wants to *understand* by involving scientific and/or scholarly methods to help generate well-founded understanding of and insight into this "something". If such a problem has not yet been dealt with satisfactorily or exhaustively by relevant communities, we typically call it a research problem, but lots of problems can be of an intellectual nature without being research problems. This is the case, for instance, with hosts of problems that students encounter within academic studies. *Problems of practice* are problems that are *troubling* or *challenging* to the life or work of people, professions, communities, organisations or societies, problems that need to be removed, overcome, reduced, or counteracted by way of effective decisions or actions of some sort.

Such problems are relevant to academia to the extent academia has something important to offer to those who struggle with them.[1]

Intellectual problems and problems of practice differ in terms of their purpose and orientation, but they certainly need not represent disjoint categories as far as content is concerned. Thus, any profession-oriented academic programme attempts to handle (some) problems of practice by converting them into intellectual problems, solving these, and eventually generating solutions to the initiating problems of practice. Conversely, discipline-oriented academic programmes oftentimes consider intellectual problems, and possible answers to them, that end up having a bearing on problems of practice.

In discussions and analyses, one often gets the impression that the type of problems people have in mind for POPW and PBL are predominantly problems of practice. Particular kinds of such problems consist of so-called *social* or *societal* problems, a.k.a. problems of social or societal *relevance*, or even *real-world problems*. Although these notions are generally ill-defined (what is, e.g., "the real world"?), such problems typically refer to themes, issues or topics that are on the agenda of politico-societal national or international discourses in a certain era. Examples include problems related to: economy; environment; climate; energy; food supply; demography; migration; social conflicts; culture(s); politics and policies; public governance; structure and organisation of society; centres of power; the functioning of legal and judicial systems; education; technology in a broad sense; safety and security; defense and warfare; infra-structure; transport; information and communication structures and systems; public health; allocation of resources; industry, business, and finance; media; and international relations, to mention just a few.

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[1] Adolphsen (1999) makes a distinction similar to, but narrower than, the distinction between problems of practice and intellectual problems. Adolphsen was affiliated to Aalborg University, which is a hub for problem-based learning in Denmark. According to Adolphsen "Practical or real problems arise from contradictions or perplexing choices between what we want and what we can do. […] Practical problems can be solved without us knowing why they are solved." (Adolphsen, 1999, p. 253). Theoretical problems "are perplexing contradictions or choices between what we know and how things are (or seem to be), or they can be contradictions between two competing theories. A theoretical problem is formulated ignorance — something which our (or my) current theories cannot explain." (Adolphsen, 1999, p. 253). While practical problems are quite like problems of practice, it is clear that theoretical problems with their requirement of being contradictions within a theory or choices between competing theories belong in the category of intellectual problems, but the latter category is broader and includes problems that are not theory-induced.

Throughout history, topics such as these have always been essential to any society, because they shape the structure, organisation and function of society and people's lives therein. But the actual ways in which they are configured and manifest themselves depend on the specific point in time when they are on the agenda as well as on their geographical distribution. This means that they typically have a marked presence in media discourses, which is probably a major reason why they are considered socially or societally relevant. All these themes and topics give rise to specific problems in different contexts and locations, at different levels and on different scales. The predominant ones are ultimately problems of practice, because they have a direct impact on society and call for actions to be designed, planned, and taken. However, they also include intellectual problems focusing on the understanding of structures, processes and mechanisms, especially in contexts where it is acknowledged that the solution of pertinent problems of practice require in-depth understanding of their nature.

It is no surprise that social and societal problems receive considerable attention within POPW and PBL as they are easily visible and recognisable and easily acknowledged as socially and societally relevant.

In contrast, intellectual problems tend to receive much less attention within POPW and PBL, probably because they are more hidden, less recognisable, oftentimes less accessible, and appear to be lacking relevance to large segments of society. We argue that this is highly problematic because intellectual problems have great educational value, oftentimes more so than problems of practice. Firstly, intellectual problems call for consciousness about the need to pose and specify a problem in such a way that it can be subjected to disciplined enquiry (Dewey, 1938; Cronbach & Suppes, 1969) leading to evidence-based conclusions, where "evidence" is relative to the domain at issue. This, in turn, involves the need for a high level of analytical and methodological clarity and understanding. Furthermore, it activates the need to address and reflect on what knowledge and evidence are – and are not – in different domains, and how knowledge can be obtained and substantiated. Ultimately, intellectual problems help us distinguish between claims that can be trusted and claims that cannot. Thus, working on intellectual problems has a significant formative value for learners.

As there is no end to the kinds of problems that can be subjected to treatment in POPW (and to a lesser extent also in PBL), one question naturally arises: What criteria can be invoked to create or select problems that are suitable for POPW? Of course, a multitude of rather different criteria can come into play. It would take us too far to provide a systematic account of such criteria. (See Olsen & Pedersen, 2008, for some such criteria.) Instead, we focus on one significant

criterion, which is pertinent to POPW, namely *exemplarity*. As regards PBL, see also Dahl et al. (2003).

According to the notion of exemplarity, the relevance of a problem-oriented project is not solely determined by the stand-alone relevance of the problem investigated but also by the insights and learning generated by undertaking the project (see, e.g., Christiansen (2001) and Blomhøj & Kjeldsen (2009)). More specifically, if the insights and the learning generated are (likely to be), of a somewhat general nature, i.e. representative of a larger class of important insights and learning going beyond the singular project at issue, this project serves as an *exemplar* for this larger class of learning and insights. A project may be representative in several different respects, e.g., concerning the (potential) generalisability of the questions posed, the objects studied, the findings obtained, or the methods employed. The extent to which a singular project may serve as an exemplar in this sense is not only a criterion for what problem-oriented projects one might choose to undertake but also a potential criterion of quality of the resulting project. Engaging in analyses and discussions of the potential for a given project to become an exemplar in one or several respects is a key element in determining the pros and cons of undertaking that particular project.

Prevalent conceptions of problem-orientation at RUC

We now turn to how the conceptions of problem-orientation have evolved since the founding years of Roskilde University. For many years since its establishment, the prevalent understanding of problem-orientation in significant quarters of the university was shaped by Knud Illeris's three-part framework for student project work (Andersen & Kjeldsen, 2015b). According to this framework, the problems studied should be relevant to the students themselves, to their educational programme, and to society. Personal relevance was intended to foster motivation and engagement, educational relevance to ensure students' qualifications, and societal relevance to orient the work towards extant social issues (Illeris 1981, Ulriksen 1997).

Here, we focus on the societal/social relevance criterion as this was the one subject to the strongest debate at RUC. Illeris stressed that the problem "should be situated within a broader—and ultimately always societal—context." (Illeris 1981, p. 100, our translation). He and others maintained that this should apply not only to the social sciences, but also to the humanities and the natural sciences, while others—as discussed by Servant (2016)— strongly objected to such a one-size-fits-all approach. As we shall see below, faculty members

affiliated with the natural sciences were particularly resistant to attempts to impose this part of the framework, or similar ideas, on "their" programme.

Olesen and Andersen (2015) provide a recent, articulate update of Illeris' point of view. They note that modern academia is characterised by centrifugal forces rather than the centripetal forces of earlier times. Furthermore,

> "Strangely, the nuclear physics paradox implied that it was precisely when science pursued science itself that it became of value to society – be it in the form of weapons or power-production –and this is still a valid argument. This example shows the extremely ambiguous and political nature of societal impact. The critical quest for truth can, on the other hand, hardly find itself an object that is not in itself interwoven with this context. The fact that the qualms of conscience experienced by theoretical physicists during the 1940s with respect to nuclear technology had such great metaphorical impact is probably because they, dramatically, showed the final profanation of pure, truth-seeking science – without any real possibility of being able to set the social and political agenda themselves." (Olesen & Andersen, 2015, p. 269)

This led Olesen and Andersen to conclude that

> "Today, the challenge is to provide a space where students can practise handling more profane versions of the relation between academic knowledge and practical competence. This relation is mediated by the students' situation and subjective engagement." (Olesen & Andersen, 2015, p. 269).

In this situation,

> "[the] argument for project studies is to create an institutional hybrid space which enables the (re-)engagement of these centrifugal forces, with the clear understanding that they will not be harmonious. 'Problem-oriented project studies' is an alternative way of opening universities to society and at the same time preserving basic academic qualities of independence, criticism and truth-seeking." (Olesen & Andersen, 2015, p. 269)

Olesen and Andersen summarise their ideas in a depiction of the study environment as a hybrid space as in Figure 1. Here, 'social challenges' is their update of Illeris' 'societal issues', the 'academic traditions' corresponds to the educational criterion, while students' 'social experience' is similar to Illeris' 'student relevance'.

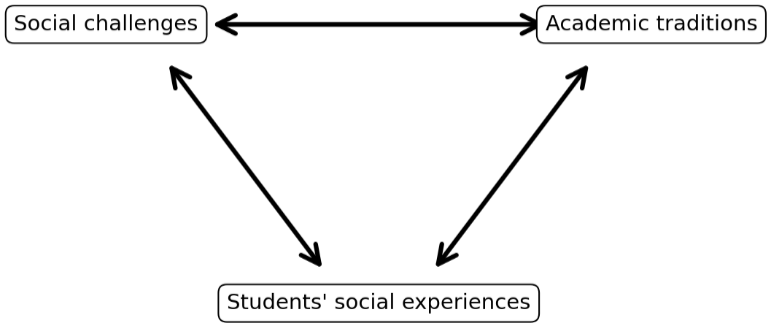


Figure 1. The study environment as a hybrid space (Olsen & Andreasen, 2015).

Olesen and Andersen clearly prioritise problems of practice within the 'intellectual/practice' distinction as they emphasise the development of students' "practical competence," as well as a need for "letting in a criterion of practical relevance." (Olesen & Andersen, 2015, p. 270) Furthermore, in their view "'Non-academic' discussions of functional and political relevance play a significant role in project work, not least through the attempts to trace the interrelation between practical epistemological issues and the theoretical and methodological questions related to traditional academic work." (Olesen & Andersen, 2015, p. 270) Their view thus implies that purely intellectual problems, and in particular discipline-related intellectual problems, should have at most a marginal position in problem-oriented work.

Over time, a shift occurred at RUC away from an emphasis on societal problems towards what is termed "real-world" problems. While all societal problems can be perceived as real-world problems such problems/issues are rarely explicitly defined. The typical usage of the term appears to align with Ulriksen's definition, according to which a real-world problem "must be something that actually occurs and occurs outside the sphere of academic study" (Ulriksen, 1999, p. 22, our translation). An example could be: "Why is it the tomato sauce that burns your mouth when eating a hot pizza?" This problem can hardly be considered a societal problem as it concerns an everyday phenomenon affecting individual experience rather than a broader social issue with consequences for the community. Nor is it within the sphere of academic study (but it can be translated into an academic problem). No matter the precise definition, the category 'real-world problems' must be broader than 'societal problems' as the former type of problems includes the latter as a proper subset.

Thus, "real-worldliness" has emerged as a prevalent criterion at RUC. For example, this is the case with the description of the principle of problem-orientation in branding material used by the university during the last decade: "The projects at RUC are oriented towards understanding and solving real world issues through the use of theory and scientific methods." (RUC, 2026a)

Moreover, RUC's so-called framework documents on interdisciplinarity stress real-world problems as the basis of problem-orientation (RUC, 2026b).

While Ulriksen's definition is neutral in regard to the intellectual/practice distinction, others (e.g., Knudsen, 2009) often understand the term 'real-world problem' to involve a concrete issue or challenge to somebody and thus eventually becomes a problem of practice.

Now, a multitude of intellectual problems reside within, or relate to, scientific or scholarly academic disciplines. Since the dawn of civilisation, such disciplines and their development have constituted the key categories by means of which humankind has conceptualised, understood, and dealt with the world. Such problems are posed, specified and handled with reference to the conceptual, theoretical and methodological frameworks that govern the discipline(s) under consideration and constitute their accomplishments. Ulriksen's definition rules out such discipline-related intellectual problems such as they occur within the sphere of academic study.

However, dealing with discipline-related intellectual problems allows learners to go into depth with the edifice of the discipline at issue and ultimately come to grips with essentials and fundamentals of that discipline. This is the reason why large parts of academic study programmes traditionally, in the past, have been centred around scientific and scholarly disciplines. However, in recent decades one can detect a growing trend, in tertiary institutions, to replace discipline-centred programmes by composite study programmes taking the shape of packages mixing different kinds of elements and being oriented towards preparing students for more or less specific professions or classes of professions. Composing such programmes is a rather flexible undertaking, as mixed programmes can easily be changed in response to changing demands and trends in society. While there may certainly be very good reasons to establish such mixed packages, this should not be taken to imply that there is then no longer any need for maintaining and developing discipline-centred study programmes in academia. In fact, dismantling such programmes would be a disastrous break-away from the accumulated, structured, and stored insights generated by centuries – sometimes millennia – of discipline-centred research and education.

Alternative conceptions of problem-orientation at RUC

Right from the beginning, alternative conceptions to Illeris's framework and its derivatives existed at RUC – in particular within the natural sciences – and thus in parallel with the prevailing conceptions of problem-orientation as involving

social/societal problems. Here, a divide emerged between two positions. One advocated that natural science programmes should provide students with in-depth knowledge and skills concerning the natural sciences as an end in itself, and that the acquisition and application of these require systematic and progressive exposure. The other position held that any such programme should instead focus on societally relevant problems; accordingly, the natural science elements should be limited to providing only sufficient understanding to allow for the engagement with these problems, and that such understanding could and should be developed in an *ad hoc* manner as needs arise in working on the problem. Many members of the natural science faculty at RUC defended the former position, in opposition to groupings who wanted engagement with societally relevant problems to serve as the central – if not the only – organising principle for all programmes. The former position argued that if serious natural science qualifications were indeed desirable, then an educational focus exclusively on societal problems would be insufficient for preparing students in the fundamental disciplines of natural science.

For instance, Gustaw Kerszman (1977) wrote about projects inspired by current political debates:

> "Such projects do not as a rule force the students to learn 'hard' science, to plan and perform experiments, to interpret their result, to test hypothesis, to use the tools of mathematics […] The students often move only on the surface of natural science and its technological applications. The projects drift almost naturally towards dilettante journalism." (Kerszman, 1977, p. 147)

In line with this view, since the late 1970's, and still today, the basic studies in natural science are organised around projects with problem formulations leading to the involvement of the natural sciences as such, see below.

Initially, following the establishment of RUC, the basic studies in the humanities — like those in the social sciences — largely focused on societal problems. Over time, however, a tension similar to that concerning the natural sciences emerged, and by 2015 Andersen & Kjeldsen could write:

> "The criterion of *social relevance* – one of the main original arguments in favour of problem-orientation – has been reinterpreted, because it has been difficult to relate some subjects in some academic cultures directly to this criterion. The social relevance criterion, in particular in the natural sciences and humanities, has gradually moved to an interpretation where the connection between the problems and the outside world passes through the problems of the academic disciplines rather than the other way round." (Andersen & Kjeldsen, 2015b, p. 24)

The argument in favour of not focusing solely on problems of social relevance is not that societally relevant problems involving the humanities and the natural sciences cannot be found. In fact, there are hosts of such problems amenable to academic treatment. The argument is rather that there are crucial aspects of the humanities and the natural sciences that will not be covered if students are only studying such problems.

The conception of problem-orientation in recent times

Against this background, in recent times, a more pluralistic view has emerged at RUC, at least judged from the official framework document on the pedagogical profile of the university, which has an inclusive view on suitable problems: they should be so-called "knowledge issues", often, but not necessarily, based on problems of practice from the real world. In general, this document uses a wide interpretation of "suitable problems":

> "Project work at Roskilde University is problem-oriented. It is aimed at identifying, illuminating, understanding, explaining and solving problems that may arise theoretically or from society and/or the environment. A problem can be defined in many ways and can take on various forms within different academic fields. Similarly, it is possible to work with problems in various ways, for example with varying emphasis on qualitative or quantitative approaches, inductive or deductive approaches, and with combinations of these approaches." (RUC, 2026c)

While problems of practice readily fit within this pluralistic framework, it also accommodates intellectual problems, including discipline-specific ones, as they arise in theoretical form.

We have already noted that this pluralism permeates the bachelor programme in natural science. It also permeates the master-level programmes. In the next section, authentic examples of projects within mathematics and physics are presented. A cursory look at some of the projects being done in the humanities in recent years at RUC tells a similar story of pluralism where students can pursue problems that are focused on understanding rather than on counteracting obstacles occurring in practice. Moreover, two researchers affiliated with the humanities at RUC, Feldt and Pedersen (2021), advocate that the problems of student inquiry in the humanities should be academic problems, i.e. problems of the academic field, connected to the academic literature etc. Such problems are very close to what we have termed intellectual problems. Hence, the view taken by Feldt and Pedersen can be seen as a further testimony of the growing pluralism in recent times.

Discipline-related intellectual problems

Against the background established above, we find it worthwhile to pay particular attention to discipline-related intellectual problems, some of which may, indeed, as already mentioned, have a significant bearing on problems of practice as well, even though they do not have to. As our backgrounds are in science and science education in general, and physics and mathematics education in particular (see also Niss (M.A.), 2001), we want to point out that there are fundamentally three kinds of intellectual problems relating to mathematics and physics – and most probably to any discipline in natural science - namely problems posed *within* the discipline, problems posed *about* the discipline, and problems dealt with *by means of* the discipline being applied outside its own domain. Problems posed within a discipline address issues that are *internal* to the discipline, ranging from singular questions of a concrete nature, over questions pertaining to the methods and techniques of the discipline and to the results it produces, to questions related to its theoretical constructs and the interrelations amongst these. Problems posed about the discipline address the nature, state and role of the discipline *as a discipline*, including its foundation, structural characteristics, general methodologies, origin, history, and philosophy, as well as its relationships with other disciplines. Finally, issues that deal with the application of a discipline to problems that are *external* to its own domain, be these problems of a scientific, scholarly or practical nature, constitute the third kind of problem. It is important to realise that problems dealt with *by means of* an academic discipline need not be intellectual problems, even though they certainly can be. However, it should also be emphasised that problems concerning the application of mathematics or physics to another scientific discipline, say biology or economics, which are not intellectual problems within mathematics or physics, may well be intellectual problems within that other discipline. The issue of exemplarity of problem-oriented projects related to an academic discipline then particularly focuses on the extent to which the project is an exemplar with regard to problems *within*, *about* or *by means of* that discipline.

We now present some intellectual problems which have actually been made subject of investigation by problem-oriented projects conducted by students at Roskilde University during the last several decades. There are several hundred examples of such projects. To keep things simple, we have chosen to present just six projects, three related to mathematics and three to physics.

We begin by considering three mathematics projects selected to illustrate the three kinds of intellectual problems introduced above.

The project *"On the strategies used to attack unsolved mathematical problems – a case study of the Collatz Conjecture"* was carried out by four mathematics students in 2015. The initiating problem statement reads as follows (original in English):

> "Given that the Collatz Conjecture is hard, what approaches have been used to attack related, but potentially easier problems? In what way can these derived problems help mathematicians settle the conjecture?" (p. 2)

The Collatz Conjecture (posed in 1938) is a problem in elementary number theory asking whether a certain process of repeated halving of the even natural numbers that arise in the process will always result in the number 1 (the conjecture). The problem is easy to understand, and no counterexample has ever been found. However, so far, despite a multitude of different attempts and approaches, no universal proof has been found either, which is what makes the problem challenging from a mathematical point of view.

This clearly is an intellectual problem posed *within* mathematics as a discipline. The four mathematics students reported their work in a 47-page project report. (Zoet, et al, 2015)

The project *"Pathological examples – on the impact of weird mathematical "fish" on the development of mathematics"* (our translation from Danish) was carried out by five mathematics students in 1993. The problem statement reads as follows (our translation from Danish):

> "What kinds of impact did [selected] pathological examples have on the development of mathematics? Why did these examples have an impact, i.e. what properties of the examples made them significant?" (our translation) (p. 3)

By "pathological examples", the project group understood a well-known collection of notorious mathematical entities with counter-intuitive and unexpected properties, typically resulting from rather complex or surprising constructions.

The problem stated deals with aspects of the development of mathematics as a science and hence is an intellectual problem *about* mathematics. The students reported their work in a 90-page project report (Dræby, et al., 1993).

The project *"The Radon transform and its application to CT-scanning"* was carried out by four mathematics students in 1993. The problem statement reads as follows (our translation from Danish):

> "How is the Radon Transform applied in relation to CT-scanning and what model assumptions lie behind this application?" (p. 8)

This project deals with the construction and use of a medical scanning device created *by means of* mathematics, in this case the so-called Radon Transform introduced by Johann Radon in 1917. The Radon Transform, which was introduced for purely mathematical purposes, takes its point of departure in a so-called real mathematical function f defined on a 3D-domain. The integrals of this function along all planes determine a new function F – the RT - defined on the set of all planes. Radon proved that given F, f can be completely retrieved. Thus, this is an example of a mathematical entity put to use in a domain (medical diagnostics) that is *external* to mathematics itself. Albeit not an intellectual problem within mathematics (Radon had already solved the mathematical problem at issue), the problem investigated – linking Computerised Tomography with the Radon transform - was in fact an intellectual problem within medical diagnostics. The students reported their work in an 89-page report (Christiansen et al., 1993).

The project *"A Study of the Role of Solvents and Chain Length in Anomalous Swelling in Phospholipid Bilayer"* is an experimental project performed by four physics students. They studied so-called anomalous swelling of bilayers of a certain type of molecules called lipids. Such bilayers are made of two layers of lipids that in water arrange themselves, such that their water-loving heads face outward, and their water-repelling tails face inward. Anomalous swelling is a surprising "extra swelling" of the layers that happens under specific conditions (like temperature changes), which cannot be explained by normal thermal expansion alone. A model developed at DTU was proposed to account for this phenomenon.

The project studied the following questions (slightly rephrased for clarity):

> Do the explanations proposed in the literature regarding the importance of salt and chain length for the anomalous swelling agree with the results we obtain when the two parameters are varied simultaneously? Do we obtain results that further support the prevalent model or contradict it? What information do our results provide about the interlamellar forces in the system? (p. 3, our translation)

The students reported their conclusions in a 129-page report (Niss et al, 2001).

This project concerns a model-based explanation of an already identified phenomenon in physics, namely anomalous swelling, and the extent to which this explanation agrees with some novel experiments performed by the project group. With its focus on matters internal to physics, it is clearly a *within* project.

While the phenomenon of "anomalous swelling" may have practical applications, with the actual scope, the project is about understanding and explaining the phenomenon without regard to the practical consequences. Thus, the problem investigated is an intellectual one.

The project *Study on the Simultaneous Discovery of the Conservation of Energy, and in particular on the Works of Mayer, Colding, Joule and Helmholtz* (our translation) was carried out by three physics students in 1992. The problem statement reads

> "On the basis of an interpretation of Mayers, Colding's, Joules' and Helmholtz's respective formulations of a general principle of the conservation of energy in one form or another, it is examined what agreement there exists between the four formulations and what prerequisites each scientist had for putting them forward." (p. 3, our translation)

In this project, the students took a historical approach and read and compared the original work on conservation of energy of the four scientists mentioned in the problem statement. Furthermore, they studied what particular knowledge enabled the scientists to put forward the conservation principle. Thus, the project sheds light on how principles may emerge in physics. The project report contains 92 pages. (Arleth et al, 1992)

This is clearly an intellectual problem *about* physics as a discipline.

Five science students carried out the project *Determination of the Rolling Resistance of Rubber Balls on a Rotating Plane* in 2015. The project studied methods for reducing rolling resistance, an important factor in lowering fuel consumption and reducing fossil fuel use. Determining rolling resistance, which causes energy loss to heat and leads to vehicle deceleration, requires simple and reliable measurement techniques. In this work, the problem statement reads

> "Can a rolling resistance coefficient be determined through experiments with a rubber ball on a rotating, hard surface, and is the method we use to determine the magnitude of the rolling resistance coefficient appropriate?" (p. 12, our translation)

Thus, this project focuses on bringing the experimental methods of physics to bear on this problem motivated by the real-world problem of reducing fuel consumption through reduced rolling resistance. Hence, it is clearly an intellectual problem in physics addressing a problem of practice by *means of* physics. The project report consisted of 95 pages (Gylling et al., 2015).

The six examples just presented show how very different intellectual problems within, about and by means of mathematics and physics have been dealt with in discipline-specific problem-oriented project work that possesses all the crucial properties characteristic of POPW. These projects gave rise to essential academic learning for the students involved. Moreover, two of the three projects also demonstrate how problems, which are intellectual from an academic perspective, can have a highly significant impact on problems of practice outside an academic context.

Concluding remarks

Given that POPW and PBL have been around and gained momentum in tertiary education for nearly sixty years, it is worth acknowledging that no overarching conceptual framework to encompass all the key aspects of POPW and PBL has been universally agreed upon. On the contrary, different – if not competing – conceptualisations and associated frameworks exist. These frameworks differ, for instance, in their emphasis on problems of practice versus intellectual problems, on socially/society relevant issues versus issues with a broader focus, on professions- versus discipline-oriented study programmes, and on skills-focused versus competence-focused study programmes.

It seems that these differences sometimes represent antagonistic positions trying to dominate "the marketplace", in some cases even to the point where certain positions exert what might be called *hegemonic reductionism* over other positions. One component in this reductionism is a single position's insistence on knowing what happens in, and is important across, all academic domains, typically leading to *coerced harmonisation* of the structure and organisation of markedly different study programmes, without paying due respect to the need for substantive knowledge of the nature and characteristics of different academic domains, a knowledge which only scholars and scientists within the respective domains possess.

We find this state-of-affairs markedly problematic and harmful to the quality of academic programmes. In line with this view, we argue that dealing with discipline-oriented intellectual problems is very important and relevant, also for problem-oriented project work within, about, and by means of academic disciplines. Our position is certainly not that such projects should be the only ones dealt with in POPW, just that they should have "civil rights" within the entire spectrum of academic programmes centred around such work. We sincerely hope that such an inclusive view may be underway at Roskilde University.

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