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Learning to Do Knowledge Work: A Framework for Teaching Research Design in Engineering Education*

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The purpose of this article is to describe and evaluate a framework for active learning to enhance research skills among engineering students. Following a tradition of experiential learning, we have developed a conceptual framework to support such learning. We use the term 'PROE' to refer to the framework suitable to characterize a research design in terms of four related aspects: purpose, research, outcome, and evaluation. The PROE framework is a model *of* as well as *for* research. It can be used to design, redesign, and evaluate a research process by involving not only the ability to apply specific techniques and follow specific procedures but also the higher-order competences of alignment and adjustment. As such, it is an educational framework, actively promoting the teaching-learning research activities in engineering education. We evaluate and discuss the effects on student learning by looking at data from personal observations, course evaluations, and student research projects. Thus, we contribute to the field of active learning in engineering education with a presentation of PROE as an educational framework for active learning to advance research in engineering education as well as an evaluation of the students' and our own (as lecturers) learning experiences.

Keywords: engineering research; teaching-research nexus; research design; alignment; adjustment

1. Introduction

The purpose of this article is to describe a framework for active learning to enhance research skills among students in engineering education and evaluate the students' learning outcomes. Engineering research has become a hugely important part of engineering education curricula. In the transition to the knowledge society, engineering students—and higher education students in general—are expected to learn to evaluate and to some extent conduct research, i.e., work with knowledge in the sense of not only being able to apply the knowledge but also assess and, to a certain degree, produce the knowledge [1–4]. However, designing a course on engineering research presents several challenges.

First, it poses difficulties in terms of *what* to teach [5, 6]. Engineering research is an enormous field that resists any simple definition or description. It crosses all engineering disciplines and subject matters and thus crosses the many methods and approaches that fall under the category of research methodology, each of which has separate and detailed literatures. Consequently, it is an impossible task to design a single course or module that covers the whole field of engineering research. It is simply not realistic to expect students to acquire, in a single course, the theoretical and practical skills enabling them to consider and conduct different kinds of engineering research. Even the limited aim of raising an awareness of engineering research leaves lecturers with the dilemma of either introducing many different types of research or merely focusing on one particular kind.

Second, designing a course on engineering research involves difficulties in *how* to teach [5]. Whereas teaching typically takes the form of a cost-effective mass lecture, researchers and educational developers have argued that we should seek new approaches to teaching research in higher education in general [3] and in engineering in particular [4] that are not only economically efficient but also educationally effective. Increasingly, researchers and educational developers have stressed the importance of recognizing differences in teaching and learning styles in general [7, 8] and active learning, such as problem-based and project-based learning, in particular [9–11]. However, we need more research on how to influence teaching and learning to enhance research skills among engineering students.

The dual purpose of this paper is to contribute to the educational development and research in this field by (a) describing a framework for active learning to support and enhance research in engineering education, combining multiple ways of relating to research in teaching, and (b) evaluating the effect on students' learning outcomes, integrating several levels of evaluation.

In the following section, we first describe the case and context of the framework in the course 'Research Design in Engineering'. Second, we out-

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line the theoretical background and inspiration in an experiential and reflective conception of active learning. Third, we describe PROE and how it is applied as a framework for active learning to enhance research skills in engineering education. Fourth and finally, we describe and discuss the effect on students' learning outcomes and suggest vistas for further development and research.

2. The context and case

Since the purpose of this article is to describe a particular framework for active learning to improve research skills among students in engineering education and evaluate the students' learning outcomes, we will briefly introduce the framework and our evaluation considerations.

The context of the study is our own practice of teaching research methodology in engineering education. More specifically, we teach the compulsory course 'Research Design in Engineering' at the MSc in Engineering study program (Technology Based Business Development) at Aarhus University, Denmark. The study program attracts students from many different countries and bachelor's degree programs, so our task is to encompass not only disciplinary differences but also cultural and ethnic differences in the course. In recent years, and in particular from 2015 to 2017, we have developed the PROE framework to actively promote the teaching-learning research activities in engineering education [12]. As mentioned above, designing a course on engineering research poses challenges in terms of *what* and *how* to teach and learn. The PROE framework has helped the students structure the general characteristics of the field (e.g., the various approaches) and assess the qualities in specific areas of research (e.g., others or their own).

Evaluating the effect of PROE as an organizing framework for a set of teaching and learning activities is not without problems. Typically, the effect or impact of learning activities is evaluated by measuring and comparing effect sizes, most often as these are assessed by the learners themselves in response to course evaluation instruments or by the lecturers in connected with examinations [13]. However, such measures should be analyzed with caution, since they are subject to the 'Hawthorne effect', whereby people knowingly react positively to an intervention, in particular if they believe that it is beneficial regardless of its actual merit [14]. Since the present study is a case study, we will also include our own experiences as course developers and lecturers. Thus, a mix of qualitative and quantitative methods for data collection is applied. First, reflective diary notes are used to describe our own observations and experiences. These qualitative data are, of course, subject to the Hawthorne effect as well, particularly since we did not take notes consistently. Nevertheless, they still represent important data about our experiences of the effects of our activities [15]. Second, student responses to the course evaluation were collected: In 2017, 26 students out of 121 responded to the evaluation, i.e., a response rate of 21.5%, which is low, however not unusual for this kind of quantitative data. Finally, we have examined student research projects, which provide very rich and detailed qualitative information about the students' descriptions of and reflections on their research. We have access to the research projects from the 2017 fall semester. Based on our qualitative notes, we will describe the context of the 'Research in Engineering' course in more detail below. The students' responses and research projects will be discussed in the final part of the paper.

In 2012, we started teaching the course 'Methods and Approaches' that used traditional textbooks on the subject. Increasingly, though, we experienced crucial limitations in the traditional textbooks and approaches, which was be based on the assumption that teaching research methodology is an add-on process to accumulation and reproduction of performance skills and competencies as well as tips and tricks. Research methods are presented as standalone procedures, apparently independent of the conceptual and practical issues that arise from studying the actual sites of the events under study. Hence, many textbooks and course descriptions are rooted in an underlying and largely unexamined epistemology of research according to which researchers are instrumental problem solvers who select technical means best suited for particular purposes. In other words, researchers solve well-formed instrumental problems by applying the theories and techniques of research methodology. But, increasingly, this is often not the case in engineering research [16]. The problems of real-world engineering research do not always present themselves as well-formed problems, and real-world research then is not just technical *problem solving* but *problem setting* as well. It is through the framing and naming of problematic situations that technical problem solving becomes possible. Depending upon their interests and perspectives, professional background, and practical purposes, researchers frame problematic situations in different ways. Professional identities and interests determine how we see a problematic situation, select things for attention, and set a direction for action. Researchers pay attention to different facts and make different sense of the facts. Consequently, research is not only a technical process but also a situational, personal, and political process. This point is increasingly being addressed in methodology textbooks, even though it typically takes the form of a brief note in the introductory chapter at the most general and abstract level in terms of philosophical positions or paradigms such as positivism, constructivism, and critical realism. Such presentations, then, tend to remain locked in a technical way of thinking, implying that philosophical positions or paradigms are frameworks to be applied. In short, we have found that textbooks tend to focus too much on the technical aspects of research methods and too little on the practical aspect of designing feasible engineering research, i.e., aligning and adjusting general methods and techniques in accordance with the purposes, problems, and political interests of the research. Consequently, in 2015, we changed the name and focus of the course from 'Methods and Approaches' to 'Research Design in Engineering' and developed the PROE framework.

Another related limitation in traditional textbooks and approaches to the subject is that they tend to be based on the assumption that information about research can be transmitted through mass lectures, i.e., taught by a lecturer who talks about research findings of (own) particular interest or about research processes by which knowledge is created to engender a research ethos. Ironically, although studying, teaching, and researching in higher education are defined by one another in substantial ways, these activities are nonetheless often separated by underlying tensions. Many textbooks tend to describe student life and research as 'worlds apart'. However, as Light and Colleagues have stressed, although "for the student, the academic world is typically new and strange, its language and practices frequently unfamiliar and mysterious, even exotic and bizarre" [17, p. 25], it is nonetheless important that lecturers seek to bridge or 'integrate' the worlds by finding ways of critically engaging students. In doing this, we have found the framework for different ways of relating to research in teaching developed by Healey [18] helpful. Healey has developed a diagrammatic model that highlights both the extent to which a course develops students' abilities to conduct research, and the extent to which a course brings students into research as participants. The model is depicted in Fig. 1.

Thus, according to Healey, teaching can be (a) *research-led* when students are taught about research findings by faculty to learn about recent research; (b) *research-oriented* when students are taught about the research processes to learn about research methods and techniques; (c) *research-tutored* when students are engaged in research discussions to learn how to assess research; or (d) *research-based* when students are invited to undertake a research project to learn how to conduct research. It is our experience that the most effective learning experience involves a combination of all four approaches, but with an emphasis that students should be active and engaged in all kinds of teaching and not only in (c) and (d).

In the following, we will outline the theoretical underpinnings of our approach before we describe the PROE framework and combine it with Healey's four ways of integrating research in the classroom.

3. Theoretical background

It is a key point in modern theories on higher education and learning that although we are natural born learners, certain types of formal education can get in the way of our will or motivation to learn and, in some respects, learning itself [19]. John Dewey was among the first to make this point more than 100 years ago. He argued that the native and unspoiled attitude of childhood, marked by curiosity, imagination, and love of experimental inquiry is very near to the attitude of the scientific mind [20]. Hence, Dewey was concerned that traditional trans-

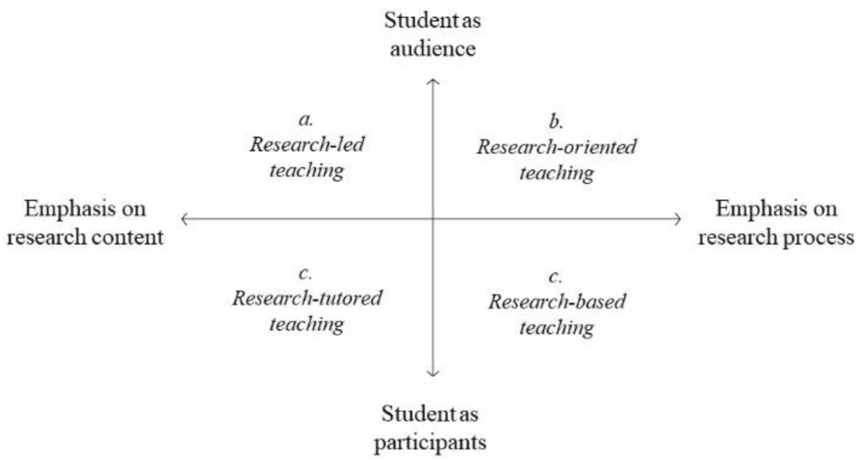

Fig. 1. Relationships between teaching and research.

mission approaches to teaching that focus on representations of 'facts' served to dull rather than engender the natural propensity of young learners to inquire and think reflectively. He promoted an understanding of learning that engages the learner actively in whatever is being learned.

Today, initiatives towards active learning in engineering education are primarily promoted with references to either problem- or project-based learning theory (PBL) or experiential learning theory [9, 10, 21]. The philosophical and pedagogical underpinnings of these theoretical traditions are distinct, and we have found it helpful to draw on both in the development of the PROE framework for active learning to enhance research skills.

Educational developers who promote PBL argue that education should emulate the way professional engineers work with real problems in real projects in order to prepare students for their future professional life as opposed to simply being able to pass examinations [22]. This is in direct continuation of Dewey's old idea that the starting point for learning should be a real-life problem or a puzzle that the learners seek to solve through experimental inquiry. As stated previously, the 'Research Design in Engineering' course is part of the MSc in Engineering (Technology Based Business Development) study program, which is organized as a PBL program. Students establish close collaborations with companies, and each semester, the students—alone or in small groups—work on at least one project that addresses a technological problem in a company. To use the terminology of Bob Ross, the curriculum is both problem-oriented, problem-based, and problem-solving [23]. In other words, students work on authentic problems from companies, and they are given time and training in order to solve these problems. Thus, engineering problems are used as selection criteria for the content, and the students work on real-life problems during the courses in which they are given specific training in solving problems. Most of the problems, though, require some kind of research. Some projects require laboratory experiments while others entail field experiments in the actual workplaces, interviews with people (experts, suppliers, customers, or other) from outside the company, etc. To support this, we have organized the 'Research Design in Engineering' course in such a way that it is the first course of the study program, and, thus, the students can work on the research design in their first company-related project as part of the course. However, we have experienced a crucial limitation in PBL in that it mainly focuses on a practical problem and to a lesser extent on the research problem, i.e., the research questions that need to be answered as part of the project. PBL tends to assume that the problem to be solved is quite clear and that the knowledge needed to solve the problem is already available; it just needs to be found [24]. Thus, its focus is on the problem-solving process. An example of this is the CDIO framework developed at MIT in the 1990s, according to which engineers conceive, design, implement, and operate (CDIO) processes, and for this reason, engineering students should be engaged in such activities. However, due to real-life complexities, the students' projects at the MSc in Engineering study program are often only loosely defined by the company to begin with, i.e., the part of the project that identifies, defines, and delimits the problem to be addressed. Moreover, the knowledge needed to conduct the project successfully is often not available; it may not even be defined or delimited, even though part of the project is to define, delimit, and produce the knowledge while at the same time considering the internal and external validity of the knowledge. Hence, it is important that students are able to define and delimit both the practical problem to be solved and the research problem, i.e., the research questions to be answered.

In order to integrate this aspect into our PBL approach, we have drawn on experiential learning theory, and more specifically, the cycle of experiential learning described by David Kolb [25]. Finding inspiration from previous theories of learning processes and general frameworks describing it, such as the PDCA (Deming) cycle and similar frameworks, Kolb describes learning as a four-stage cycle: experience, reflection, abstraction, and action. The model is depicted in Fig. 2.

Thus, immersion in concrete experience (CE) is viewed as the basis for reflective observations (RO), which is assimilated into a general idea or abstract conceptualization (AC) from which implications for experimental action (EA) may be derived, leading to new concrete experiences, etc. Although the cycle describes learning from experience in general and not learning about research in particular, we have found it helpful as a theoretical inspiration. First, like Dewey, Kolb places concrete experience at the beginning of the learning process, and, as a result, the cycle can help us go beyond the tendency in many research textbooks and courses to rely too heavily on ACs and expect the concepts to be transmitted to the students. Second and again in accordance with Dewey, Kolb stresses the importance of RO and EA as a kind of mediators between CE and AC, and thus, the cycle can help us address research in a way that goes beyond the application of methods and techniques. Skilled researchers do not simply apply methods and techniques but employ them in such a manner as to devise a research design and modify it in appro-

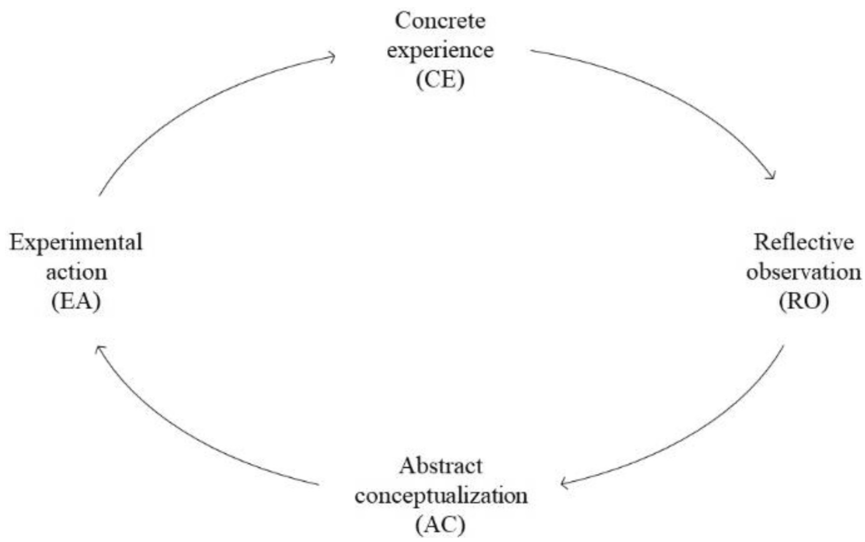

Fig. 2. Experiential learning.

priate ways if needed. In a memorable description of 'the reflective practitioner', Schön [26, 27] distinguishes between the high ground and the swampy lowlands as illuminating metaphors. We find these metaphors particularly illuminating in regards to research: In the varied landscape of research, there is a high and hard ground overlooking a swamp. On the high ground, clearly defined problems lend themselves to solution through the application of theory and technique, whereas in the swampy lowland, messy and confusing problems defy technical solution. Thus, lecturers in research methodology must choose. Should we remain on the high ground where we can solve simple issues by applying simple techniques, or should we descend to the swamp of important problems and complex inquiry? The irony of the situation is that the problems of the high ground tend to be very limited, however rigorous the technical solutions may appear, while many engineering issues lie in the swamp. A problem for real-world research often presents itself as a unique case. Because the unique case falls outside the categories of existing theory and techniques, it cannot be treated as an instrumental problem to be solved by applying theoretical or technical knowledge. In other words, what students need most to learn in terms of research, courses seem least able to teach. As Schön describes it, the unique case "is not in the book" [27], and therefore, if we are to deal with it, we must create reflection and experimentation through which research questions are stated and appropriate research designs are suggested. In other words, the focus on RO and EA allows for an understanding of research as ongoing cycles of learning.

4. The PROE framework for active learning to enhance research skills

To avoid the transmission pedagogy and technical rationality of the traditional textbooks and teaching about research, we have shifted the original focus and emphasis of the course from 'Methods and Approaches' to 'Research Design in Engineering'. The concept of research design signifies the arrangement of elements or details. A good design is one in which the components work harmoniously together to promote efficient and successful functioning. In addition, a good design not only fits its use but also its environment. Some textbooks focus on research design too, even if they tend to present research design as a plan of prescribed stages or tasks in conducting a study. Although some textbooks mention that research designs are circular and recursive, they nonetheless show a preference for presenting research designs as essentially linear, i.e., as an unidirectional sequence of steps from problem formulation to conclusion. In a research process, however, any component of the design may need to be reconsidered or modified during the study in response to new developments or to changes in a component. This process is not adequately represented by a linear model of stages, even if it allows multiple cycles, because there is no fixed order in which the different activities or components must be arranged, nor is there a linear relationship among the components of a research design. One needs to continually assess how the research design is actually working during the research, assess how it influences and is influenced by the context, and make alignments and adjustments, all in an effort to ensure that the study accomplishes its purpose. In

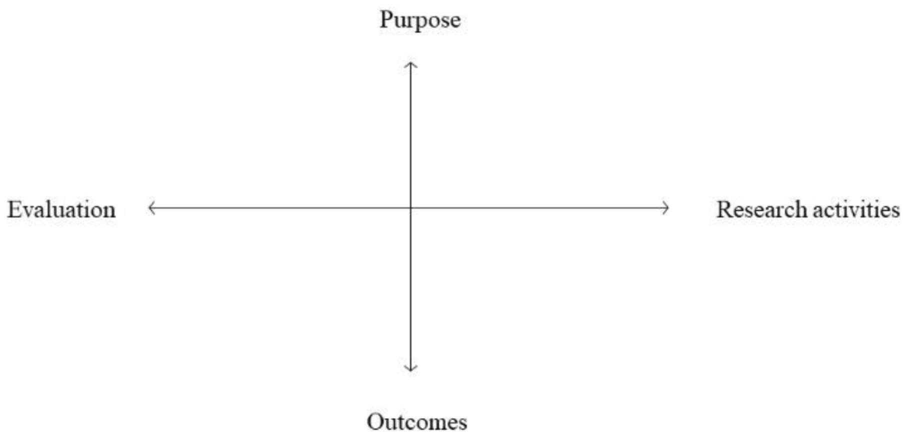

Fig. 3. The PROE framework.

other words, the focus on 'research design' helps us stress that a good design is developed in a design process, and a research design, then, is not just a plan but an activity. It is about the reflective and experimental design of a study.

We structure active learning to enhance research skills among students in engineering education. We have developed the PROE framework, which, as previously stated, is short for purpose, research, outcomes, and evaluation. The framework is depicted in Fig. 3.

While linear or typological approaches to research design provide a prescriptive guide that arranges the tasks involved in conducting a study, the PROE framework presented here is a model *of* as well as *for* research. It helps design (and redesign) a study. In designing a research study, one cannot just develop a plan in advance and then expect to implement it accordingly. Quite the opposite, one needs to devise and revise a research design in ongoing cycles to a substantial extent. Although the PROE framework is interactive in the sense that despite its definite structure (P-R-O-E), it is flexible, and thus, the importance does not lie in where to start but rather in the aspects being aligned.

The framework has helped us make this point and organize several learning activities around it. The course runs seven weeks during which the students are offered 14 lectures concurrently with developing a research design for a project. Before and during lectures, the students are given examples of engineering research to discuss and relate to their own project. Thus, following Healey [18], we organize both *research-led teaching* in which the lecturer briefly presents 2–3 examples of engineering research designs (literature reviews, laboratory experiments, field experiments, or interview studies), and *research-oriented teaching* where the lecturer briefly introduces the methods and techniques that are being used in the studies and addresses their typical strengths and weaknesses. Student activity in these traditional approaches to teaching is limited to asking questions. To activate students more, we engage them in a more thorough *research-tutored teaching* with student discussions focusing on a specific study. In these discussions, the students are asked to use the PROE framework to consider the appropriateness of the research design, i.e., to consider the alignment of the purpose, research activities, outcomes, and evaluation in the study. Finally, this is followed by *research-based teaching* in which students are asked to consider the relevance of the particular research design in their own project and discuss (in groups of 2–3 students) how the individual student might design a similar study for their own project and how this would influence the purpose, research activities, outcome, and evaluation of the study. Student activity in these student-centered approaches is increased substantially. In the discussions, students have the opportunity to actively test their understanding, and in their research projects, they are expected to test and develop it even further when considering the appropriateness of their research design.

The 'purpose' is an important component in a research design, and formulating research questions that address the purpose of a study is often seen as a key task. The purpose serves to justify a study, i.e., it shows people why the study is important. Not all studies have an explicit statement of the research purpose, but every good research design contains an implicit or explicit identification of some issue or problem, about which more knowledge is wanted. In many textbooks, research questions are presented as the starting point and primary determinant of the research design. However, this does not adequately capture the interactive nature of research problems. In most cases, we cannot come up with well-grounded research questions without making use of other components of the design.

The 'research activities' are another important part of a research design and are often seen as the key to research. Such activities are not limited to data collection and analysis, but also include establishing research relationships with people involved in the study, negotiating access, selecting sites and participants, etc. Unfortunately, as described above, many textbooks are based on an instrumental model for research activities. At the end of the day, there is no cookbook for research. The appropriate answer to any general question about the use of research methods is 'it depends', since any decision about research activities depends upon the other components of the design. The many methods that one can read about in the literature then do not represent different ways of doing the same thing but different options with different strengths and logics. Thus, they are best used to address different kinds of questions and goals. For instance, quantitative methods tend to see the phenomenon under study in terms of variables; they view research as a demonstration that there is a statistical relationship between different variables. Qualitative methods, on the other hand, tend to see the phenomenon under study in terms of detailed descriptions; they see research as a demonstration of the phenomenon's many nuances.

The 'outcomes' of research is a third important component of a research design. It is the insights and knowledge (i.e., the results) produced by a study. Research can produce many different kinds of insights on business issues, e.g., measures of the effects of particular interventions, descriptions of complex cases, explanations of behavioral patterns, understanding of particular ways of thinking research, etc., some of which differ radically in their assumptions and implications. It is well known that expectations and the assumptions embedded within them can distort research by forming a pre-established framework, which can make it difficult to see that a new way of framing the insight might contribute more. Thus, it is important to identify both the insights that particular assumptions can provide as well as the limitations or blind spots.

The 'evaluation' is a fourth important design component. Research is evaluated in terms of its validity, which is not a context-independent property of methods, and thus, never something that can be proven or taken for granted on the basis of the methods used. As Brinberg and McGrath put it, "Validity is not a commodity that can be purchased with technique" [28]. Most philosophers have abandoned the view that methods could and should guarantee validity, but it still informs many textbooks asserting that research can ultimately be reduced to the application of techniques. However, validity is a property of inferences rather than methods, and therefore, it is inferred from the circumstances of the research. The concept of validity is controversial, and some scholars have rejected the concept entirely, e.g., some qualitative researchers who find it too closely tied to quantitative research. Thus, we prefer the more neutral term 'evaluation', since this signifies what research designs should do, namely give some ground for distinguishing accounts that are credible from those that are not. Evaluation as a component of a research design consists of the conceptualization of strengths and weaknesses, validity, and a description of how those weaknesses are dealt with or taken into consideration when drawing conclusions.

Often, the starting point of research is a purpose, but this is not always the case, and in all circumstances, the original purpose is often revised and restated during a study in accordance with the research activities and outcomes or any of these if they are evaluated and assessed to be inadequate. Designing a study then involves not only the ability to apply specific techniques and follow specific procedures but also the higher-order competence of alignment. In addition, the components of the PROE framework are not only interrelated (for which reason they must be aligned); they also interact, and consequently, they must be adjusted in the research process. For instance, it is often the case that the real and important problem is only delimited and defined during the research process. In other words, designing a study involves both the higher-order competence of alignment as well as the higher-order competence of adjustment—which then calls for realignment. The higher order competences are depicted in Fig. 4.

Through the teaching and learning activities described above, the students develop a tentative research design for their project during the course, which is the subject of the examination. The examination is conducted as an individual oral examination where the student presents a research design and discusses its strengths and weaknesses, i.e., whether it is appropriately aligned and adjusted to the context. Upon course completion, the students continue to work on their projects and the research designs until they conclude their project with an examination at the end of the semester. As the students often continue their collaboration with the same company throughout the study program, they work on related topics in a new project in the subsequent semester.

In the final part of the paper, we describe and discuss the effects of the teaching and learning activities organized around the PROE framework on the student's learning outcomes. In addition, we suggest vistas for further development and research.

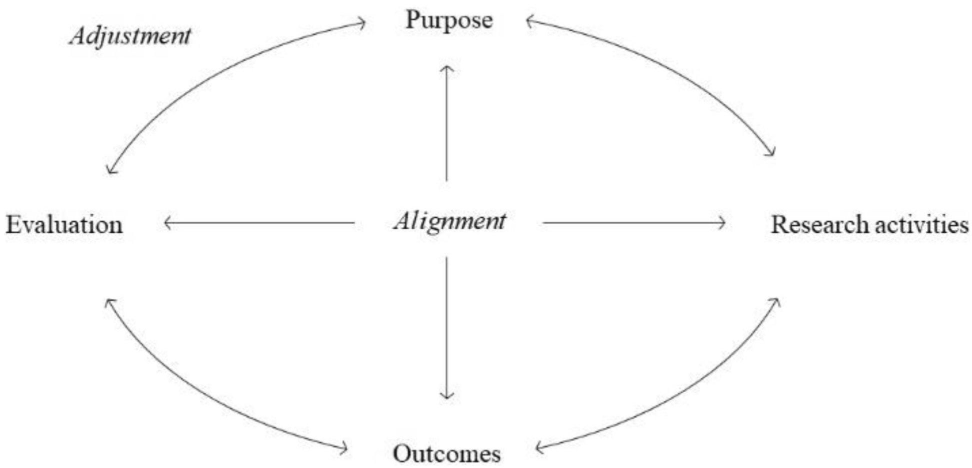

Fig. 4. Alignment and adjustment as higher-order competencies.

5. Discussion of the effects on students learning outcomes

In this final part of the paper, we discuss the effects of the PROE framework for active learning on the students' learning outcomes. First, we share our personal observations as lecturers in terms of the PROE framework enabling students' learning outcomes, and second, we discuss the effects based on the standard survey conducted as an evaluation of any course as well as our own survey about the PROE framework specifically. Finally, we discuss the effects of the PROE framework based on a qualitative analysis of the students' skills and competencies, as these are evident in their research projects.

The purpose of the 'Research Design in Engineering' course is to enable students to evaluate research and conduct small-scale research in the form of a relevant and coherent research design in a research project. We use the PROE framework to facilitate a mixed set of teaching and learning activities. Our evaluation activities have focused on the various aspects of the students' learning. Through the qualitative observation-based evaluation, we found that the students use of the PROE framework and their related learning in the classroom. In the survey-based evaluation, the students evaluated their overall learning and some also the role of the PROE framework. Having read student projects from subsequent courses, we have evaluated the students' actual use of the PROE framework.

5.1 Observation-based evaluation

The PROE framework has increased the students'—and our—interest in the lectures; the students are much more engaged and participative than they used to be. PROE has helped us organize the teaching and learning about research in engineering education in a way that engages students and encourages participation. More specifically, the PROE framework has helped us combine research-led and research-oriented teaching with research-tutored and research-based teaching as a means to enhance the active learning of the students and thereby enrich their learning experience. The PROE framework stresses that both research and learning involve reflective and experimental action, and therefore, teaching research does not begin from a predetermined starting point or proceeds through a fixed sequence of steps; it is a reflective practice involving continuous alignments and adjustments between different components. In other words, research involves the interconnection and interaction among different design components. Consequently, we have organized the course with the aim of providing a flavor and feel of research through interactive discussions of a range of different kinds of engineering research designs between the students as well as active and reflective experimentation with possible research designs in the students' individual projects. The student discussions and experimentation with a mix of nationalities and cross-disciplinary backgrounds allow for cultural differences in the teaching and research practices to emerge. It is our experience that for some students, this is an extraordinary learning experience; for others, it is more a 'learning shock', which Griffiths and colleagues have described as an "acute frustration, confusion and anxiety experienced by some students [. . .] [who] find themselves exposed to unfamiliar learning and teaching methods, bombarded by unexpected and disorienting cues" [29]. Such frustration and confusion are readily understandable when we acknowledge that learning is an emotional experience, and this is a focal point for further development and research.

5.2 Survey-based evaluation

Student frustration also appears in the 2017 course evaluation. When discussing the student responses to the course evaluation survey, it is important to take some reservation in interpreting the results due to the low response rate and the risk of a Hawthorne effect [15]. With that being said, the students are generally happy about the course. Table 1 shows an excerpt from the survey-based course evaluation.

As Table 1 shows, all respondents state that they benefit from the course (Q1), and a third of the students indicate that they benefit greatly. The students also state that they are very pleased with the PROE framework. Three out of four state that PROE has improved their basic understanding of engineering research design (Q14). However, some of the qualitative comments indicate that the course and the framework also frustrate a few students. One student in particular noted, "PROE is a research framework that is used only at Aarhus University. I could not find any similarities or implementation at other universities or in businesses. So I strongly recommend that the course lecturers choose an applied real-world research framework or one that the majority of academic researchers use in order to teach future master students something useful, instead of using a self-invented framework, which will only help the students get a good grade and nothing more." To us, this comment illustrates at least two important points: First, that students are concerned about their professional career and do become frustrated when experiencing that what they learn is not 'useful' in the sense of being applied outside of the university, which is only fair. The second point is that we might have stressed the actual framework too much rather than the intention underlying it. The intention of PROE is not to apply it as a general framework everywhere, like the PDCA (Deming) cycle, the SECI cycle, or similar frameworks [30], but to enhance reflective and experimental learning about research. Thus, the important point in the PROE framework is not the acronym itself, but that it fosters reflection on and experimentation with alignment and adjustment of research design components. Although more than half of the students found that the PROE framework has improved their understanding of different types of research design (Q15), and almost half of the students found that the framework has improved their understanding of different types of research activities (Q16), this is not the main purpose of PROE. The framework does not describe procedures or techniques, but rather prescribe a reflective and experimental approach to the *design* of research, and thus, helps organize a diverse set of teaching and learning activities. The survey-based evaluation shows that more than half of the students found that the activities allowed them to test the understanding and correct mistakes and misunderstandings (Q4) as well as allowed for feedback and supervision on the students' work (Q5). Almost three out of four students found that the lectures initiated fruitful discussions with fellow students (Q8). In general, most of the students participated actively in the learning activities, and almost everyone was satisfied with the communication in the lectures (Q11), which indicates that the activities are somewhat effective in engaging the students. However, finding more strategies to increase student engagement will remain a focal point for further development and research.

5.3 Evaluation of student research projects

Whereas our experiences and observations as well as the students' course evaluation responses all pro-

Table 1. Excerpt from the survey-based course evaluation

	Strongly agree	**Agree**	**Neither nor**	**Disagree**	**Strongly disagree**
Q1. I have benefitted from the course.	34.6%	65.4%	0%	0%	0%
Q4. Lecturers allowed me to test my understanding and correct mistakes and misunderstandings.	23.1%	38.5%	26.9%	7.7%	3.8%
Q5. Lecturers allowed for feedback and supervision on my work.	19.2%	34.6%	26.9%	19.2%	0%
Q8. Lecturers have allowed for fruitful discussions with fellow students.	26.9%	46.2%	19.2%	3.8%	0%
Q9. I have involved myself actively in the learning activities in and between lectures.	11.5%	42.3%	34.6%	3.8%	7.7%
Q11. Lecturers were good at communicating the subject.	34.6%	57.7%	7.7%	0%	0%
Q14. PROE has improved my understanding of the fundamentals of engineering research design.	16.7%	61.1%	5.6%	5.6%	11.0%
Q15. PROE has improved my understanding of the different types of research design.	0%	55.6%	33.3%	5.6%	5.5%
Q16. PROE has improved my understanding of the different types of research activities.	0%	38.9%	38.9%	16.7%	5.5%

vide useful information about the effects of the teaching and learning activities, it is even more relevant and interesting for us to look at the students' research projects to see if there are observable effects on the behavior. More specifically, we want to examine *how* students conduct research in their projects, having completed the 'Research Design in Engineering' course. According to the Kirkpatrick Model [13], 'behavior' represents a higher level of effect than both student 'responses' (to evaluation surveys) and a teacher's evaluation of the students 'learning' (tested in examinations). We have access to student research projects from the 2017 fall semester of which almost half of the students refer explicitly to the PROE framework. When comparing exam results of those using PROE and those who do not, we do not find any significant differences between the two groups. This, however, is not surprising, since introducing the PROE framework is not the explicit reference to the acronym itself, but the reflective and experimental approach to the design of research that it fosters. In other words, reflection on and experimentation with research design components can easily be included without explicit reference to the framework. When we look at the research design or the research methodology chapter in the projects, we notice that the students seem to have become more reflective and experimental than they used to be. A major rationale for the PROE framework is that a good design is one in which the components work harmoniously together, whereas a flawed design leads to poor operation or failure. A design is a 'bricolage', a term originally coined by Levi-Strauss [31] to describe the creative process of using available tools and materials to create a solution to an unique problem. Bricolage means 'do-it-yourself', and a research design is exactly that. The bricoleur does not follow a pre-fixed plan but adapts to the circumstances of the situation, creatively employing the available tools and materials to find solutions to unique and often complex problems. However, this does not mean that we endorse an 'anything goes' approach to a research design; the different implications of diverse designs and assumptions need to be relentlessly pursued. Thus, part of designing research is not only to seek the broader understanding that can be gained from juxtaposing diverse approaches but also to systematically test one's approaches and premises against alternatives. As a flexible toolkit of different methods and 'lenses' for understanding the phenomena we study, this is both a more logical and a more productive stance than locking ourselves into a pre-stated plan or paradigm. Research purpose, activities, outcome, and evaluation should form an integrated unit in which these components are clearly linked. Currently, there is no instrument to measure research skills and thus measure the effect [32]. Hence, this opens a vista for further development and research in the field.

6. Conclusions

In this article, we have argued that courses on engineering research involve difficulties regarding *what* and *how* to teach and learn. We have contributed to overcoming these difficulties by (a) describing the PROE framework for active learning about research in engineering education, and (b) evaluating the effect on students' learning outcomes.

Regarding (a), the PROE framework stresses that research involves four interrelated aspects of a research design: The purpose of the research, the research activities, the outcomes, and an evaluation of strengths and weaknesses of the research design. A major rationale for the PROE framework is that a good design is one in which the components work harmoniously together whereas a flawed design leads to poor operation or failure. The PROE framework, then, does not describe procedures or techniques, but prescribe a reflective and experimental approach to the *design* of research, and hence helps organize a varied set of teaching and learning activities. Based on the framework, we have organized a course with the aim of providing a flavor and feel of research through interactive discussion of a range of different kinds of engineering research designs between the students as well as active and reflective experimentation with possible research designs in the students' individual project. The implications of diverse designs and assumptions need to be relentlessly pursued. Rather than following a pre-fixed plan, students are encouraged to adapt to the circumstances of the situation, creatively employing the available tools and materials to create solutions to unique and often complex problems. The PROE framework helps identify both the general characteristics of the field, e.g., the manifold approaches, and assessment of the qualities in specific pieces of research, e.g., others or their own.

Regarding (b), we have evaluated the effect of the PROE framework on students' learning outcomes through a mix of qualitative and quantitative methods. First, we have used reflective diary notes to describe our own observations and experiences as these have been put down in notes and discussed among us. Second, we have used a survey to evaluate student responses to the course. Finally, we have looked at research project reports from the following courses, which provide very rich and detailed qualitative information about the students' descriptions of and reflections on their research. The main findings in the evaluation are:

- The PROE framework has helped us combine research-led and research-oriented teaching with research-tutored and research-based teaching as a means to enhance the active learning of the students and thereby enrich their learning. When we look at the research design or research methodology chapter in the reports, we notice that the students seem to have become more reflective and experimental than they used to be.
- The students are much more engaged and participative than they used to be. Many find that the activities have allowed for them to test the understanding and correct mistakes and misunderstandings as well as allowed for feedback and supervision on the students work. And most of the students find that the lectures have allowed fruitful discussions with fellow students.
- The students state that they benefit from the course, and many state that the PROE framework has improved their basic understanding of engineering research design. In particular, the framework has improved their understanding of different types of research design and different types of research activities.

The PROE framework will continue to be a focus point for further development and research. One issue for further development and research will be the learning experience of the students. Another issue for further development and research will be how student engagement can be increased further. A third issue for further development and research will be how to measure research competencies and the effects of active learning initiatives.

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