Problem-based projects in medical education

extending PBL practices and broadening learning perspectives

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Published in:
Advances in health sciences education : theory and practice

DOI (link to publication from Publisher):
10.1007/s10459-019-09917-1

Publication date:
2019

Document Version
Accepted author manuscript, peer reviewed version

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ArticleTitle	Problem-based projects in medical education: extending PBL practices and broadening learning perspectives	
Article Sub-Title		
Article CopyRight	Springer Nature B.V. (This will be the copyright line in the final PDF)	
Journal Name	Advances in Health Sciences Education	
Corresponding Author	Family Name	**Stentoft**
	Particle	
	Given Name	**Diana**
	Suffix	
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Schedule	Received	9 April 2019
	Revised	
	Accepted	31 August 2019

Abstract

Medical education strives to foster effective education of medical students despite an ever-changing landscape in medicine. This article explores the utility of projects in problem-based learning—*project-PBL*—as a way to supplement traditional case-PBL. First, project-PBL may enhance student engagement and motivation by allowing them to direct their own learning. Second, project-PBL may help students develop metacognitive competencies by forcing them to collaborate and regulate learning in settings without a facilitator. Finally, project-PBL may foster skills and competencies related to medical research. As illustrated through a brief example from Aalborg University, Denmark, students learn differently from project-PBL and case-PBL, and so one implementation cannot simply replace the other. I conclude by suggesting future directions for research on project-PBL to explore its benefits in medical education.

Keywords (separated by '-')	Active learning - Case-PBL - PBL - Problem-based learning - Projects - Project-PBL - Student-centred learning
Footnote Information	

Journal : SmallCondensed 10459	Article No : 9917	Pages : 11	MS Code : 9917	Dispatch : 8-10-2019

Advances in Health Sciences Education
https://doi.org/10.1007/s10459-019-09917-1

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Diana Stentoft[1]

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Abstract

Medical education strives to foster effective education of medical students despite an ever-changing landscape in medicine. This article explores the utility of projects in problem-based learning—*project-PBL*—as a way to supplement traditional case-PBL. First, project-PBL may enhance student engagement and motivation by allowing them to direct their own learning. Second, project-PBL may help students develop metacognitive competencies by forcing them to collaborate and regulate learning in settings without a facilitator. Finally, project-PBL may foster skills and competencies related to medical research. As illustrated through a brief example from Aalborg University, Denmark, students learn differently from project-PBL and case-PBL, and so one implementation cannot simply replace the other. I conclude by suggesting future directions for research on project-PBL to explore its benefits in medical education.

Keywords Active learning · Case-PBL · PBL · Problem-based learning · Projects · Project-PBL · Student-centred learning

Introduction

In 2019 we celebrate 50 years of problem-based learning (PBL) in medical education: 50 years of putting students first in the learning process, and 50 years of making patients the primary learning resource. It also marks an apt time to review what PBL has contributed to medical education, and how various implementations of PBL have changed the way medical competencies are developed.

Such reflections on PBL are not new. More than 30 years ago, Howard Barrows outlined a taxonomy to explore the many possible forms of PBL and how they promote different learning objectives (Barrows 1986). This taxonomy focused on several variables to categorize a given instantiation of PBL, including the structuring of problems and whether learning is student- or teacher-directed. Since then, other authors have similarly created taxonomies to categorize implementations of PBL according to key variables related to

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Journal : SmallCondensed 10459 | Article No : 9917 | Pages : 11 | MS Code : 9917 | Dispatch : 8-10-2019

student engagement, teacher engagement, and the nature of problems (e.g. Savery 2006; Savin-Baden 2014). These taxonomies all share the view that PBL is tied to narrow learning objectives where teachers and facilitators delimit the scope of learning through specific case materials and prescribed learning steps. However, PBL can be more than this.

By closely examining the birth of PBL across four leading PBL universities around the world, Servant (2016) found that PBL emerged by two distinct means. On one hand, in medical schools at McMaster University and Maastricht University, PBL was organized around patient cases developed by teachers, and students learned through well-constructed steps. In sharp contrast, at Aalborg University and Roskilde University, PBL emerged around the same time, but was organized around open-ended and student-centred projects running over extensive periods of time and supported by project supervisors. For consistency, I will hereafter refer to these two strategies as case-PBL and project-PBL, respectively.

After 50 years of PBL predominantly centred around patient cases in medical education, it is perhaps time to re-examine the merits of project-PBL. This re-examination is timely, especially because of changing demographics and aging populations, access to vast amounts of information, and increasing pressure placed on health care systems.

Little research has discussed the challenges and implications of project-PBL as a means to complement case-PBL or other traditional approaches in medical education. The present paper sparks this discussion by exploring how project-PBL differs substantially from case-PBL. To further elucidate how project-PBL may be integrated into undergraduate medical curricula, an implementation at the medical school of Aalborg University in Denmark is presented. The paper concludes with a brief discussion of further research that aims to shift project-PBL from the status of innovative practice into an evidence-based approach, fostering the development of new competencies. As these points are elaborated below, it is important to note that project-PBL is not being proposed as an alternative to case-PBL, but instead as an innovative approach that may foster supplementary skills and competencies, especially those pertaining to research.

PBL as cases and projects

Project-PBL and case-PBL are both founded upon similar theoretical principles about learning. Problems are seen as the entry point to the learning process, student collaboration is thought to enhance learning, teaching is organized as facilitation and supervision, and students are required to take responsibility for their own learning (Barrett and Moore 2011; Barrows 1996; Davis and Harden 1999; Hmelo 2004; Laursen 2013; Savery 2006; Savin-Baden and Major 2004; Schmidt 1983). Similarly, both approaches to PBL are based on assumptions about students being active, self-directed, and bringing their prior experiences into the learning process. Thus, as noted by Barrows (1986), PBL addresses learning objectives that are often not addressed in more conventional approaches. These objectives include the structuring of knowledge and reasoning, learning to be self-directed, and refining an understanding of learning needs or motivations. AQ1

Therefore, it is not theoretical assumptions about learning that distinguish project-PBL from case-PBL, but rather learning objectives and the nature of problems with which students learn. Project-PBL is aimed at students reaching learning objectives stated in abstract and open terms, often inviting students to work in interdisciplinary learning spaces (Stentoft 2017). This means learning objectives in project-PBL can focus on theoretical as well as methodological aspects of medical research. Hence, projects typically do not include detailed

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descriptions of activities because the broad learning objectives must be defined by the students themselves in collaboration with their project supervisor. In contrast, learning objectives in case-PBL are typically defined much more narrowly; for example, with respect to a specific organ system, patient group, or disease (MacDonald 1997). Hence, in case-PBL, specific scenarios or patient stories are created using carefully designed 'problem triggers' to ensure students can reach prespecified learning objectives in a structured manner, normally assisted by a facilitator (Wood 2003; Gijselaers 1996).

Addressing further distinctions between project-PBL and case-PBL, Kolmos (2009) and Helle et al. (2006) point to several variables that differ between the two approaches. These are especially related to the scope of problems and the time spend on each problem. For example, projects in project-PBL are open ended, leaving it up to students in collaboration with their project supervisor to identify, justify, and define the problem they are working on, and to present a rationale for the scientific relevance of the problem (Thorndahl et al. 2018). Projects are typically carried out over an extended period in which students coordinate their projects in collaboration with their supervisors (Holgaard et al. 2014). On the contrary, in case-PBL, case materials developed by teachers delimit the spaces within which students can locate the problems to be addressed, and thus the scope of any case is intended to fully frame what students will learn. The period for working with a case is often limited to one week and pre-defined steps are followed.

The two approaches also differ in terms of assessment. For case-PBL, students strive towards the shared goal of delivering a written product. Working with cases offers students a unique experience to learn from peers while using prior experiences to construct new knowledge. But students usually are not working towards any shared goal or written product. This is reflected in the step often referred to as 'private study time' that occurs between cases (David et al. 1999; Dolmans and Schmidt 2010). For project-PBL, however, students strive towards the shared goal of delivering a written product. To ensure fairness, group exams are often used however each individual student is assessed on their performance in relation to learning objectives originally set out for the project. So although the joint written project forms the basis for discussions, it is the responses of each student that determines their final grade. A study by Kolmos and Holgaard (2007) suggests that such group-based exams assess students on complex knowledge, but also helps them reflect on their scientific work and the team processes. This way of assessing students is also aligned with a study on collaborative assessment, which pointed to the importance of clarity in expected learning outcomes and opportunities for each student to demonstrate their learning (Elliot et al. 2012).

Table 1 summarizes the key characteristics of project-PBL and case-PBL discussed thus far. The two approaches clearly differ in many important aspects. In general, the practices of project-PBL and case-PBL differ significantly, with the former arguably affording students more autonomy and control over their own learning (de Graff and Kolmos 2003). It would therefore be unreasonable to assume that students could gain the same knowledge, skills, and competencies from either approach. This will be discussed further. However, now we will move from abstract descriptions to the actual practice of project-PBL in medical education. We will do this through a brief description of project-PBL as it unfolds at the medical school of Aalborg University, Denmark.

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Table 1 Comparison of case and project PBL in medical education

	Case PBL	Project PBL
Duration of PBL activity	1 week	Up to one entire semester
Learning objectives	Narrow aimed at students developing specific skills or acquiring specific knowledge	Broad aiming at students developing skills and competencies to explore scientific problems
Learning outcome	Clinical reasoning and knowledge acquisition	
Framing the problem	Through cases constructed by teachers	Through students defining a specific scientific problem from a broader theme
Role of students	Active during pre-scheduled case sessions and during activities and group meetings supporting the case learning	Organising the learning process, group meetings, meetings with supervisor, experiments and other activities required to address the problem defined
Role of facilitators	Facilitating learning during prescheduled case sessions	Facilitating and supervising learning when requested by the project group during the project period
End product	Individual or group notes to the extent that students find this useful	Written project report for which the entire group is responsible
Assessment	Individual through written or oral exams	Individual assessment based on shared written report and performance at group-based oral defence of the report

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Integrating both project-PBL and case-PBL into medical education: Aalborg University as an example

Aalborg University was founded in 1974 as a new Danish university. From the outset, the university adopted project-PBL as an institutional approach to learning. PBL was regarded as a way of realising a constructivist and student-centred vision for learning, inspired by such prominent thinkers as John Dewey, Jean Piaget, and Oscar Negt (Illeris 1974; Servant 2016). Though the educational context has changed considerably since its establishment, Aalborg University remains a dedicated PBL university today. This is reflected in the university aiming for approximately 50% of all student activity to be centred around project-PBL work in most studies offered.

The principles of PBL at Aalborg University state that the problem is starting point for learning, and that learning is a collaborative process anchored in student groups. The principles further state how students are responsible for their own learning while being supported by one or more supervisors. It is also emphasized that problems must be exemplary and scientific. Problems must therefore reflect situations realistic and authentic within an academic field or relevant to a profession (Askehave et al. 2015; Kolmos et al. 2004). Just as when the university was first established, the reason for sustaining PBL through projects is to focus education on the future professions of students, and to promote metacognitive skills by having students engage with authentic and complex problems. Thus, PBL is seen as a strategy for enhancing student employability, focusing on the skills and competencies necessary to bring science into professional contexts. This is reflected in competencies such as the ability to be self-directed, to collaborate, and to initiate and organize learning when encountering complex real-life problems (Askehave et al. 2015).

Consequently, use of PBL was taken as a given when Aalborg University was granted a medical education program in 2006, and the real question was *which* implementation of PBL would be best. Considerations of the advantages and disadvantages of both project-PBL and case-PBL resulted in a 10-step case-PBL model, framed around implementations at McMaster University and Maastricht University. During the six-year undergraduate program, however, students also encounter project-PBL on five occasions, constituting a workload equivalent to approximately 1.33 years of study. For example, the first project occurs in the second semester over three consecutive weeks and is set within the domain of public health. The final project occurs in the final year of study over the course of an entire semester (half a year) and focuses on clinical research (AAU 2017, 2018). Through such projects, students encounter open and complex problems related to various fields in medicine and medical research. The intention is to offer students a chance to practice transferring their knowledge to new settings (Laursen 2013), to develop skills in core medical disciplines, and to manage projects that resemble to real medical research. To deliver their written reports, students must collaborate in groups of up to eight peers, and are expected to handle knowledge gaps and overcome obstacles during the project period. Groups are allocated a project supervisor with expertise in their field of medical research, but the responsibility for making use of supervision in the most effective way is shared by the group. Figure 1 below presents a journey resulting from project-PBL.

To make Fig. 1 more concrete, here I provide an example of a project delivered at the end of the third year. In collaboration with their supervisors, one of whom specialize in clinical pain research and consult on sport-related injuries, a project group of 4 students set out to examine the effects of running on pain perception. In their project the group first present the background for their interest in the field of running and pain, then formulate

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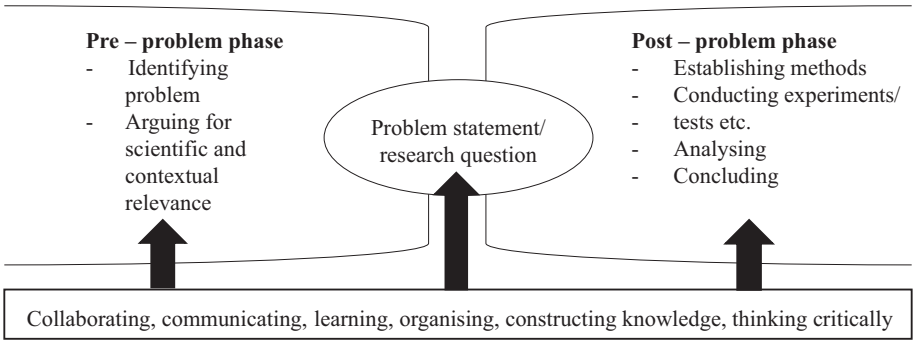

Fig. 1 A model of the problem-based project process in medical education

an argument as to why the perception of pain might decrease after a 5-km run. Based on their work the project group eventually construct the following problem statement, which they subsequently address in the post-problem phase of the project through experiments and tests. "The aim of this study was to investigate whether the pain perception will be decreased after a run of 5 km for healthy individuals in the age group 18–30 years." (Schreiner et al. 2018, p. 10). This project allows students to use medical problems to acquire new knowledge, which was one of the broad learning objectives stated in the curriculum. Other learning objectives related to the third year project specified how students must argue for a choice of scientific methods, assess results and hypotheses, then present project findings. Moreover, the learning objectives state that students must demonstrate the competencies to collaborate, to organize projects addressing complex medical problems, and to work with empirical research (AAU 2017). Student assessment was based on the group written report and via the oral examination. Grades were individual based on each students' performance at the oral exam. To ensure high-quality assessment, an external examiner from another medical school in Denmark partook in the assessments.

The role of projects in medical education

How does project-PBL add value to the medical curriculum? Potential benefits of project-PBL will be discussed below. However, it is first important to note that for project-PBL to function properly, there must exist sufficient scaffolding of learning, active students, and supervisors willing to trust students to organize learning without a pre-set schedule (Kolmos et al. 2008). In project-PBL it is not possible for students to skip class and simply prepare prior to exams. Students must instead be engaged throughout the entire process—otherwise there will be no final project to deliver for assessment!

If these prerequisites are met, one potential benefit of project-PBL is that students may be more motivated. Both project-PBL and case-PBL were found to motivate students at Aalborg University, but students clearly found projects more motivating than cases (Stentoft et al. 2014). This is consistent with research from Maastricht University suggesting benefits of progressively more self-directed learning to combat "PBL fatigue" among students working exclusively with cases (Czabanowska et al. 2012; Moust et al. 2005). Moust and Roebertsen (2010) further suggest implementation of PBL can gradually move towards projects in order for students to control their learning, collaboration and organisation independently and thus develop skills as lifelong learners. Such meta-cognitive skills

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(i.e., knowing how to best learn) are paramount to success in the complex and chaotic clinical setting beyond undergraduate medical education (Berkhout et al. 2018).

The ability to self-regulate learning processes has also been shown to predict student performance. How supervisors support students as self-regulated learners is thought to be critical (English and Kitsantas 2013).

For both project-PBL and case-PBL, student motivation is assumed to be derived from autonomy of learning, which naturally is greater when students assume responsibility for their own learning. This was reported in a study that compared student experiences of autonomy between project-PBL and case-PBL. The study found no difference student motivation, but students in project-PBL perceived their learning environment as more supportive of autonomy, and it was suggested that this occurred because problems in project-PBL appeared more authentic due to them being broader and lacking a single correct answer (Stefanou et al. 2013). In project-PBL, student autonomy is especially visible in the use of more open-ended projects towards the end of one's studies. This line of thinking is well aligned with Self Determination Theory first presented by Deci and Ryan (2002), which contends that intrinsic motivation relies on notions of autonomy, competence, and relatedness. Though project-PBL may offer more autonomy and greater relatedness through student collaboration, students are also more likely to feel a more incompetent during projects than when working with cases, because cases are narrower in scope and thus students are less likely to stray into unfamiliar new disciplines. This underpins how project- and case-PBL may offer quite different learning spaces.

As indicated above, whether using project-PBL or case-PBL, meta-cognitive competencies are often cited as a goal of education, and emphasizing these competencies has sparked debate. With the introduction of case-PBL, issues of ensuring that medical students leave university with the essential medical knowledge came to permeate educational debates because less time and resources are devoted to well-structured lectures and laboratory work, instead encouraging students to reflect and define their own learning needs. This caused concerns that PBL may be superficial and that students will lack comprehension of basic sciences (Lyon 2009). In contrast to this view, Lyon has suggested that PBL in medical education invites students to be critical thinkers; to explore the boundaries, scopes, and limitations of medical knowledge. However, this can only be realised insofar as the problems are sufficiently ill-defined and students are supported in exploring uncertain grounds (Barrett et al. 2011; Lyon 2009; Lähteenmäki and Uhlin 2011). Project-PBL speaks to this issue because it requires students to identify for themselves the problem from which they will learn about medicine, and in collaboration with supervisors, they develop not only new ways of thinking but a shared written product.

Interestingly, a study by Galand et al. (2012) compared a mixed case-PBL and project-PBL implementation to a conventional engineering education and found that the mixed PBL approach elicited superior acquisition and application of knowledge. This is interesting given that research into the effects of case-PBL alone has yielded varied results in terms of knowledge acquisition. Thus, the study suggests that project-PBL may foster competencies not only relevant to learning basic sciences, but also to applying knowledge to complex problems. This is also consistent with the idea that project-PBL resembles some of the roles and associated competencies (e.g., as communicator, collaborator, researcher) on which medical students will eventually be assessed when moving into postgraduate medical education (e.g. Frank et al. 2015; Sundhedsstyrelsen 2013). In this sense, it can be argued that supplementing case-PBL with project-PBL allows students to extend the range and scope of their learning, helping them apply their medical knowledge to increasingly complex situations.

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As mentioned above, one main intention of integrating project-PBL into medical education is to ensure students develop research competencies that are needed in their future professions. In a systematic review and meta-analysis of medical students' participation in research, it was found that students taking part in research exhibited greater scientific productivity and interest in research. The study further indicated that there is a need to standardize the research process in medical education so that students are involved in the entire research process, including the development of methodologies and data analysis. However, it was also found that student research cannot be automatically assumed to lead to students authoring scientific publications (Amgad et al. 2015). Project-PBL may offer such a standardized approach for integrating research skills and competencies into the medical curriculum via research projects. But it is also essential to note that this requires resources and the availability of researchers who are committed to work with students (Laidlaw et al. 2012).

A final potential benefit of project-PBL in medical education is related to the problem itself. When using case-PBL, the underlying intentions are characterized as students either acquiring knowledge of basic sciences, or developing clinical reasoning skills relevant to diagnosing and treating patients. This is reflected in the problems being created by planners and facilitators to ensure students move along a specific learning trajectory (Charlin et al. 1998). The intentions behind project-PBL are somewhat different. This is reflected in learning objectives focused not simply on knowledge acquisition, but also on methods and skills necessary to carry out scientific experiments, as well as competencies to apply, analyse, evaluate, and synthesize results. That is, the open-ended nature of project-PBL is intended to push students towards evaluating and synthesising across disciplinary domains, and hence to navigate the qualitative part of the SOLO taxonomy. Project-PBL thus supports the development of competencies to organize research and to manage the path towards completion of an entire cycle of research (de Graff and Kolmos 2003). Here, focus is on thinking beyond disciplinary boundaries, and evaluating and synthesizing knowledge into a new whole (Biggs and Tang 2009).

Although project-PBL may offer new perspectives and opportunities in medical education, the uncovering of its potentials and pitfalls has only just begun. Project-PBL and case-PBL differ significantly; not just in organization, but also in putative learning outcomes for medical students. These differences should be considered carefully before introducing projects into the curriculum. Critically, it has been suggested that introducing projects in the later stages of medical education could mitigate PBL-fatigue and a slow erosion of the PBL curriculum (Czabanowska, et al. 2012; Moust and Roebertsen 2010; Moust et al. 2005). Even if this is indeed the case, it requires a change of mindset regarding what it means for medical students to learn, and how they are expected to navigate knowledge, skills, and competencies at the end of their undergraduate education. These considerations raise the issue of project-PBL being sensitive to organizational challenges and student attitudes. Orchestrating collaborative research in project groups over weeks and months requires both commitment and stamina for students and supervisors. Students must tackle conflict and scientific disagreements, and supervisors must be willing to commit themselves to supporting the group while not controlling the work process. For many supervisors, this relinquishing of power and control can be uncomfortable, and for some an insurmountable barrier to fulfilling the role of supervisor (Savin-Baden and Major 2004).

I reiterate that research on the effectiveness of project-PBL in higher education is almost non-existent, making it difficult to conduct systematic reviews or other forms of knowledge synthesis (Galand et al. 2012). One possible reason for this lack of research is the complex and student-driven nature of project-PBL. Namely, work in project-PBL is organized by students over long periods of time, and at locations—both physical and digital—beyond

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the direct observations of supervisors and researchers. There is therefore a dire need to develop new research methodologies if such dynamic learning processes are to be understood. Specifically, research must be done to examine whether project-PBL promotes the specific research competencies in medicine, and whether supplementing case-PBL with project-PBL enhances metacognitive skills in medical students that affect their entry into clinical practice.

Conclusion

In this article, project-PBL is proposed as a pedagogical innovation. I argue that project-PBL in medical education broadens student metacognitive competencies and foster skills relevant to medical problems and research. I also emphasize that project-PBL should not be seen as a competitor or alternative to traditional case-PBL, but rather a timely supplement to produce well-rounded doctors.

References

AAU. (2017). *Curriculum for B.sc. in medicine faculty of medicine*. Aalborg University. https://studieordninger.aau.dk/2019/14/780.

AAU. (2018). *Curriculum for M.sc. in medicine: faculty of medicine*. Aalborg University. https://studieordninger.aau.dk/2019/17/901.

Amgad, M., Tsui, M. M. K., Liptrott, S. J., & Shash, E. (2015). Medical student research: An integrated mixed-methods systematic review and meta-analysis. *PLoS ONE, 10*(6), e0127470.

Askehave, I., Prehn, H., Pedersen, J., & Pedersen, M. T. (2015). *PBL—Problem-based learning Aalborg*. Denmark: Aalborg University.

Barrett, T., Cashman, D., & Moore, S. (2011). Designing problems and triggers in different media. In T. Barrett & S. Moore (Eds.), *New approaches to problem-based learning revitalising your practice in higher education* (pp. 18–35). New York: Routledge.

Barrett, T., & Moore, S. (2011). An introduction to problem-based learning. In T. Barrett & S. Moore (Eds.), *New approaches to problem-based learning revitalising your practice in higher education* (pp. 3–17). New York: Routledge.

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. *Medical Education, 20*(6), 481–486.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: a brief overview. *New Directions for Teaching and Learning, 68,* 3–12.

Berkhout, J., Helmich, E., Teunissen, P., van der Vleuten, C. P. M., & Jaarsma, A. D. C. (2018). Context matters when striving to promote active and lifelong learning in medical education. *Medical Education, 52,* 34–44.

Biggs, J., & Tang, C. (2009). *Teaching for quality learning at university* (3rd ed.). Maidenhead: Society for Research into Higher Education & Open University Press.

Charlin, B., Mann, K., & Hansen, P. (1998). The many faces of problem-based learning: A framework for understanding and comparison. *Medical Teacher, 20*(4), 323–330.

Czabanowska, K., Moust, J. H. C., Meijer, A. W. M., Schröder-Bäck, P., & Roebertsen, H. (2012). Problem-based learning revisited, introduction of active and self-directed learning to reduce fatigue among students. *Journal of University Teaching & Learning Practice, 9*(1), 1–13.

David, T., Patel, L., Burdett, K., & Rangachari, P. (1999). *Problem-based learning in medicine*. London: The Royal Society of Medicine Press Limited.

Davis, M. H., & Harden, A. (1999). AMEE Medical education guide no 15: Problem-based learning—A practical guide. *Medical Teacher, 21*(2), 130–140.

Deci, E. L., & Ryan, R. M. (2002). *Handbook of self-determination research*. Rochester: University of Rochester Press.

de Graff, E., & Kolmos, A. (2003). Characteristics of problem-based learning. *International Journal of Engineering Education, 5*(19), 657–662.

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Dolmans, D., & Schmidt, H. (2010). The problem-based learning process. In H. van Berkel, A. Scherpbier, H. Hillen, & C. van der Vleuten (Eds.), *Lessons from problem-based learning* (pp. 13–18). Oxford: Oxford University Press.

Elliot, M., Howard, P., Nouwens, F., Stojcevski, A., Mann, L., Prpic, J. K., et al. (2012). Developing a conceptual model for the effective assessment of individual student learning in team-based subjects. *Australasian Journal of Engineering Education, 18*(1), 105–112.

English, M. C., & Kitsantas, A. (2013). Supporting student sefl-regulated learning in problem- and project-based learning. *Interdisciplinary Journal of Problem-Based Learning, 7*(2), 128–150.

Frank, J. R., Snell, L., & Scherbino, J. (Eds.). (2015). *CanMEDS 2015: Physician competency framework*. Ottawa: Royal College of Physicians and Surgeons of Canada.

Galand, B., Frenay, M., & Raucent, B. (2012). Effectiveness of problem-based learning in engineering education: A comparative study on three levels of knowledge structure. *Internatioal Journal of Engineering Education, 28*(4), 939–947.

Gijselaers, W. H. (1996). Connecting problem-based practices with educational theory. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bringing problem-based learning to higher education: Theory and practice*. San Fransisco: Jossey-Bass.

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education: Theory practice and rubber sling shots. *Higher Education, 51*(2), 287–314.

Hmelo, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.

Holgaard, J. E., Rybert, T., Stegeager, N., Stentoft, D., & Thomassen, A. O. (2014). *PBL: Problembaseret læring og projektarbejde ved de videregående uddannelser*. Copenhagen: Samfundslitteratur.

Illeris, K. (1974). *Problemorientering og deltagerstyring: oplæg til en alternativ didaktik*. Odense: Fyens Stiftsbogtrykkeri.

Kolmos, A. (2009). Problem-based and project-based learning. In O. Skovsmose, P. Valero, & O. Ravn Christensen (Eds.), *University science and mathematics education in transition* (1st edn ed., pp. 261–280). New York: Springer.

Kolmos, A., Du, X., Holgaard, J. E., & Jensen, L. P. (2008). *Facilitation in a PBL environment*. Aalborg: Publication for Centre for Engineering Education Research and Development.

Kolmos, A., Fink, F. K., & Krogh, L. (2004). The Aalborg model: Problem-based and project-organized learning. In A. Kolmos, F. K. Fink, & L. Krogh (Eds.), *The Aalborg PBL model* (1st ed., pp. 9–18). Aalborg: Aalborg University Press.

Kolmos, A., & Holgaard, J. E. (2007). Alignment of PBL and assessment. *Journal of Engineering Education, 96*(4), 1–9.

Lähteenmäki, M., & Uhlin, L. (2011). Developing reflective practitioners through pbl in academic and practice environments. In T. Barrett & S. Moore (Eds.), *New approaches to problem-based learning revitalising your practice in higher education* (pp. 144–157). New York: Routledge.

Laidlaw, A., Aiton, J., Struthers, J., & Guild, S. (2012). Developing research skills in medical students: AMEE Guide no. 69. *Medical Teacher, 34*(9), 754–771.

Laursen, E. (2013). PPBL: A flexible model addressing the problems of transfer. In L. Krogh & A. A. Jensen (Eds.), *Visions challenges and strategies: PBL principles and methodologies in a Danish and global perspective* (pp. 29–46). Aalborg: Aalborg University Press.

Lyon, M. L. (2009). Epistemology, medical science and problem-based learning: intruducing an epistemological dimension into the medical-school curriculum. In C. Brosnan & B. S. Turner (Eds.), *Handbook of the sociology of medical education* (pp. 207–224). Oxon: Routledge.

MacDonald, P. J. (1997). Selection of health problems for a problem-based curriculum. In D. Boud & G. Feletti (Eds.), *The challenge of problem-based learning* (2nd ed., pp. 93–102). New York: Routledge.

Moust, J., & Roebertsen, H. (2010). Alternative instructional problem-based learning formats. In H. van Berkel, A. Scherpbier, H. Hillen, & C. van der Vleuten (Eds.), *Lessons from problem-based learning* (pp. 129–140). Oxford: Oxford University Press.

Moust, J., Van Berkel, H. J. M., & Schmidt, H. G. (2005). Signs of erosion: Reflections on three decades of problem-based learning at Maastricht University. *Higher Education, 50,* 665–683.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *The Interdisciplinary Journal of Problem-Based Learning, 1*(1), 9–20.

Savin-Baden, M. (2014). Using problem-based learning: New constellations for the 21st century. *Journal on Excellence in College Teaching, 25*(3&4), 1–24.

Savin-Baden, M., & Major, C. H. (2004). *Foundations of problem based learning* (p. 2004). Buckingham: Society for Research into Higher Education & Open University Press.

Schmidt, H. G. (1983). Problem-based learning: Rationale and description. *Medical Education, 17*(1), 11–16.

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Schreiner, M. P., Bruun, S. R., Liljenberg, C. K., & Svendsen, J. L. (2018). *The effect of run on pain perception—B.sc. medicine 6th semester*. Aalborg: Aalborg University.

Servant, V. F. C. (2016). *Revolutions and re-iterations*. Riddekerk: Ridderprint BV.

Stefanou, C., Stolk, J. D., Prince, M., Chen, J. C., & Lord, S. M. (2013). Self-regulation and autonomy in problem- and project-based learning environments. *Active Learning in Higher Education, 14*(2), 109–122.

Stentoft, D. (2017). From saying to doing interdisciplinary learning—Is PBL the answer? *Active Learning in Higher Education, 18*(1), 51–61.

Stentoft, D., Duroux, M., Fink, T., & Emmersen, J. (2014). From cases to projects in problem-based medical education. *Journal of Problem Based Learning in Higher Education, 2*(1), 45–62.

Sundhedsstyrelsen. (2013). *De 7 Lægeroller*. www.sst.dk Sundhedsstyrelsen.

Thorndahl, K., Velmurugan, G. & Stentoft, D. (2018) The significance of problem analysis for critical thinking in problem-based project work. In Sunyu, W., Kolmos, A., Guerra, A., & Weifeng, Q. (Eds.). *7th International research symposium on PBL: innovation, PBL and competences in engineering education*. Aalborg: Aalborg Universitetsforlag.

Wood, D. F. (2003). ABC of learning and teaching in medicine—Problem based learning. *British Medical Journal, 326,* 328–330.

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