

6 PROBLEM-BASED LEARNING IN ENGINEERING EDUCATION (PBL)

6.1 RESEARCH GROUP PROFILE

The research group of Problem-Based Learning in Engineering and Science forms the research core of the Aalborg Centre for Problem-Based Learning in Engineering, Science and Sustainability under the auspices of UNESCO (hereafter referred to as the Aalborg PBL Centre).

6.1.1 Research

Mission and vision

The vision of the Aalborg PBL Centre is that graduates from engineering and science educational institutions around the world are empowered to contribute to more democratic and sustainable societies by means of problem and project-based learning (PBL). Our mission is to generate a research capacity to support and develop high-quality PBL engineering and science education with consideration of cultural, institutional and individual diversity.

Research strategy, areas and topics

From the very beginning, the Aalborg PBL Centre's research strategy has combined *Engineering Education Research (EER)* with the study of PBL practices in engineering education as a response to ongoing societal challenges and requirements. Research on *management of change* and development of curricula systems, as well as the interaction between educational design and *professional practice*, have been cornerstones in this research focus. This scope should still be seen as a strategic and fundamental focus of the centre, although in recent years, there has been an increased focus on *science, technology, engineering and mathematics (STEM)* at the levels of primary and secondary education, continuing education and *education for sustainable development (ESD)*. Our contribution to the department and the faculty is to link educational design with capacity building in the areas of sustainability and IT.

In 2014, the Aalborg PBL Centre was established as a centre under the auspices of UNESCO, and this vision has been developed to include *digitalised learning* as a distinct research area of the centre as a response to the rapid development of digital and potentially disruptive technologies. This effort is combined with possibilities of relating learner-centred methodologies to new emergent technologies in engineering and science, such as Artificial Intelligence (AI) and the Internet of Things (IoT).

FIGURE 6.1

The six core themes connected to PBL research, see more information on current research at <https://www.ucpbl.net>

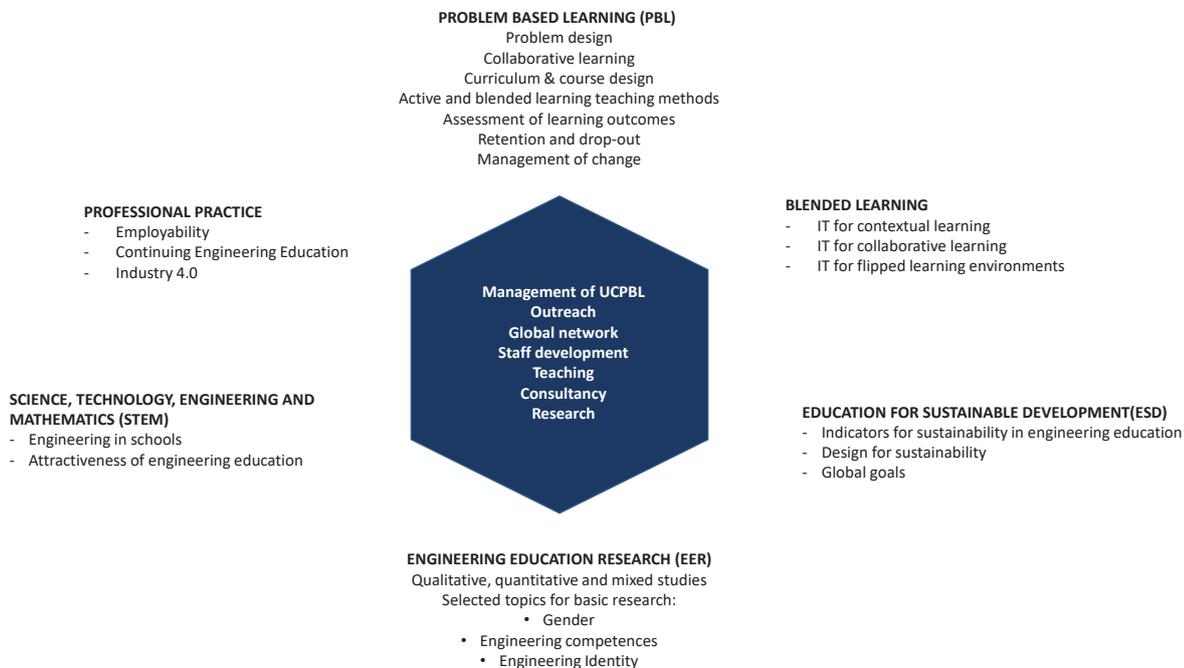


Figure 6.1 shows an overview of the core themes connected to PBL research as formulated in the 2018 research strategy. The middle of the figure illustrates the activities the Aalborg PBL Centre is performing as a UNESCO centre, which is more comprehensive compared to many other research groups. We are in a process of developing this research strategy, so the more elaborated version will be found in the future research strategy.

Research group organisation, composition and finance

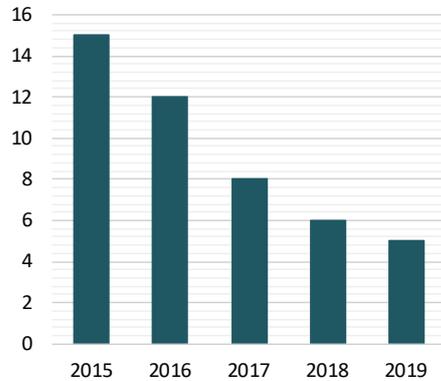
The organisation of the research group matches the organisation of the Aalborg PBL Centre, which has an international advisory board and a consultative committee (<http://www.ucpbl.net/about/organisation>). Thereby, the research group serves as a facilitator of a wide network organisation combining PBL researchers in Engineering and Science to practitioners and PBL researchers from other faculties.

Figures 6.2–6.6 illustrate the staff composition. In staff development, there has been a decrease in the number of professors from three in 2015 to one in 2019, whereas the number of associate professors has increased proportionally to the decrease of professors. The number of assistant professors is relatively stable, whereas there has been an increase in postdocs, internally financed PhDs and other scientific personnel. In total, the groups have developed from being almost 10 FTE in 2015 to almost 15 FTE in 2019.

However, in terms of PhDs, the group has had a considerable high number of PhDs for which all expenses (including wages) are paid by other research institutions (see figure 6.2). Taking this into consideration, there has in fact been a decrease in the number of PhDs from 15 in 2015 to 7 in 2016, similar to a general decrease in intake of PhDs.

Concerning gender distribution, the group has a majority of female employees, as only about one third are males, whereas the age distribution is rather equal. We are aware of this, and are working on bringing in more men to balance the gender distribution. Regarding staff's nationality, about two out of

FIGURE 6.2
Number of PhD students including PhD students financed by other research institutions, 2015–2019



ten employees are of another nationality than Danish. This is a new situation, as before 2015, we had a lot of international PhD students.

The age distribution is rather well-balanced (figure 6.5), but we are well aware that a recruitment process should be established for another, younger professor.

FIGURE 6.3
Staff development in full-time equivalent (FTE), 2015–2019

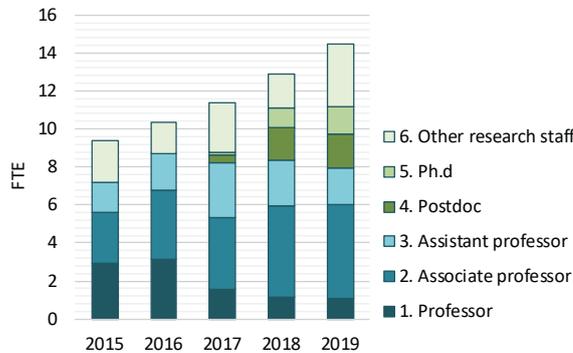


FIGURE 6.4
Gender distribution by year, 2015–2019

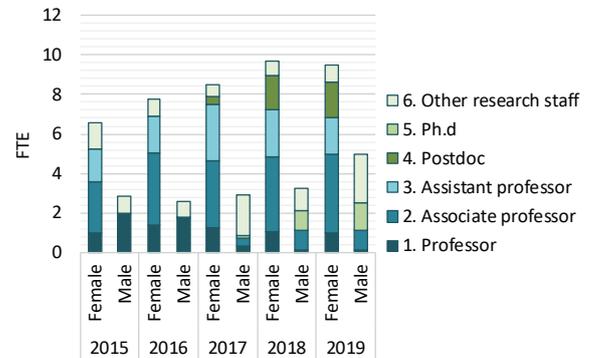


FIGURE 6.5
Age distribution compared to position, 2019

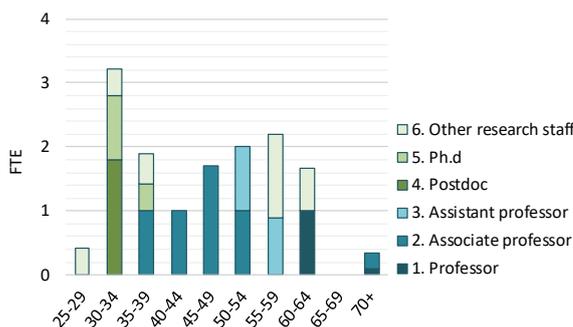
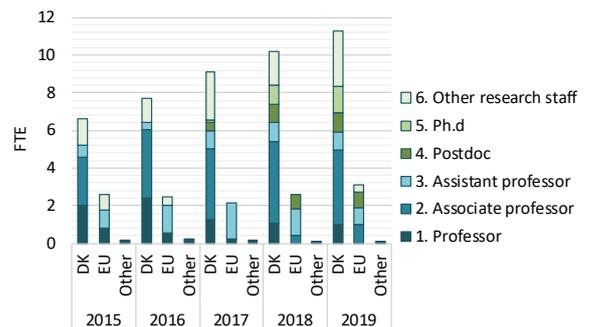


FIGURE 6.6
Nationality compared to position, 2015–2019



6.1.2 Funding

FIGURE 6.7
External funding income by year, 2015–2019

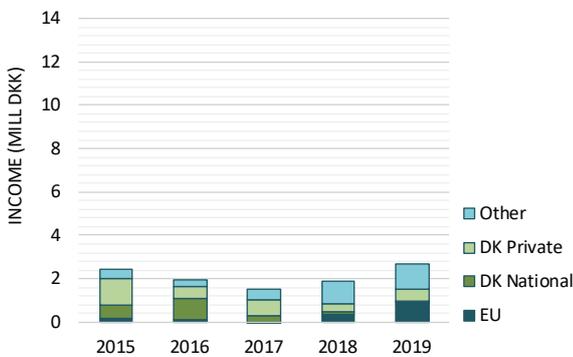
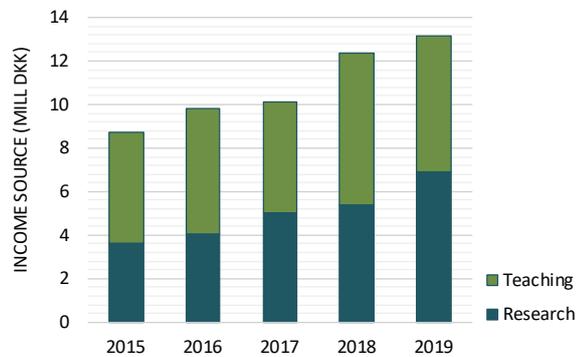


FIGURE 6.8
Internal funding by year, 2015–2019



Figures 6.7 and 6.8 illustrate the funding of the group. External funding for the group has been relatively stable since 2015, adding up to around DKK 2 million. Internal funding has been increasing, mainly due to a strategic research project 'PBL-future' which was initiated by the AAU management across faculties and headed by the Aalborg PBL Centre. Every year, the Aalborg PBL Centre received around DKK 2 million from the two engineering and science faculties.

6.1.3 Teaching

The research group carries out research-based teaching in PBL across engineering and science faculties at AAU (the Technical Faculty of IT and Design – TECH and the Faculty for Engineering and Science – ENG). The core activity is a course in PBL in Science Technology and Society (B.Sc., first semester), Contextual Co-Supervision and Consultancy (B.Sc., second semester) and introduction courses to PBL and Project Management (M.Sc., first and second semesters). The research group also contributes to AAU's staff development by delivering courses (compulsory and elective) and pedagogical co-supervision in the pedagogical programme for assistant professors (in Danish: *Adjunktpædagogikum*). We do not 'owe' our own education, but it contributes to existing programmes managed externally to the department.

Besides the internal staff development teaching activities, the Aalborg PBL Centre is responsible for an international master's programme, Master of Problem-Based-Learning in Engineering and Science (MPBL), and certification programmes. The AALBORG PBL CENTRE group also provides open courses on *Introduction to PBL*, *Problem Design and Facilitation*, which provide basic knowledge and support to academic staff from AAU and other institutions.

Finally, yet importantly, the group is involved in PhD education which, besides supervision, includes general PhD programmes, e.g. in PBL, Professional Communication, Project Management and Mixed Methods for Educational Research.

6.2 RESEARCH PRODUCTION AND QUALITY

The Aalborg PBL Centre's research production encounters research publications as well as other outputs from research projects, e.g. guidelines and online resources. The research production and quality is elaborated on in the Aalborg PBL Centre's annual reports, see <http://www.ucpbl.net>

6.2.1 Research output and weighted impact

FIGURE 6.9
Peer reviewed publications by year, 2015–2019

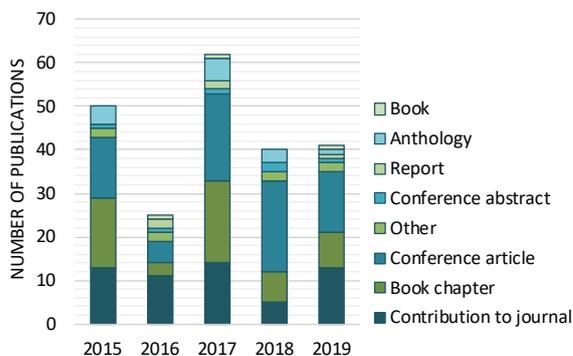


FIGURE 6.10
Bibliometric points (BFI) by year, 2015-2019



The group produces approx. three peer reviewed publications per FTE, which is considered satisfactory. For publications recognised on the bibliometric research indicator (BFI), there is an approximately equal distribution of BFI points from level 1 and 2 publications, which is in alignment with the current and future publication policies – leaving room for publications which have considerable outreach and act as a spin-off activity of knowledge sharing, as well as best-practice publications. Adding to this perspective, the research group has been editing and contributing to various international books, which is important for the Aalborg PBL Centre as a key player in the global PBL research society. To expand the outreach and impact on educational practice, the Aalborg PBL Centre has also initiated publications in languages other than English, e.g. Spanish and Chinese.

FIGURE 6.11
Field-Weighted Citation Impact by year, 2015–2019

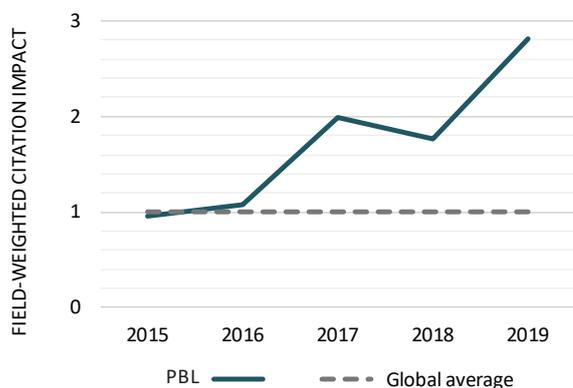
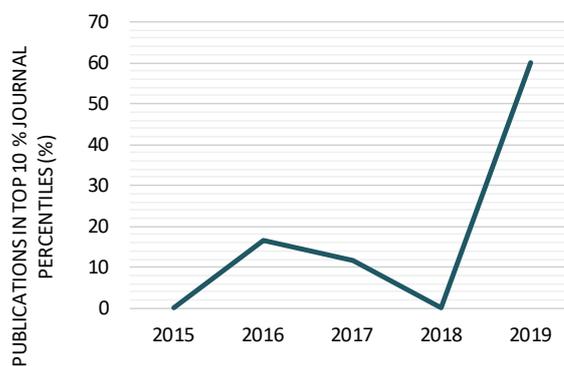


FIGURE 6.12
Publications in Top Journal by year, 2015-2019



Figures 6.11 and 6.12 indicate the citation impact. It is important to note that this is based on Scopus, and that many of the conference proceedings have not been registered in this database, but are visible on google scholar.

6.3 COLLABORATION AND OUTREACH

The Aalborg PBL Centre organises and participates in a variety of activities aiming at the dissemination of PBL research, capacity building and academic staff development, and in collaboration with local, regional and international partners. For the last 11 years, the Aalborg PBL Centre has been organising the International Research Symposium on PBL (IRSPBL) in collaboration with international partners and in conjunction with other societies, such as Active Learning in Engineering Education (ALE), Project Approaches in Engineering Education (PAEE), Research on Engineering Education Society (REES), and interdisciplinary societies such as PAN-American Society for PBL (PANPBL). Additionally, the academic staff participate in many international conferences and have been invited to a great number of keynotes and workshops at conferences all over the world. We focus on two types of conference especially: 1) engineering education conferences, such as International Research Symposia on PBL in Engineering and Science, European Society for Engineering Education (SEFI), and American Society for Engineering Education (ASEE), and 2) education for sustainable development, such as the European Roundtable of Sustainable and Cleaner Production (ERSCP) and the Engineering Education for Sustainable development (EESD) conferences. Additionally, the research group has a range of international staff development programmes – ranging from a master’s in Problem-Based Learning in Engineering & Science (MPBL) to institutionally targeted excellence and certification programmes and visitor workshops. Furthermore, the Aalborg PBL Centre is engaged in outreach activities as the regional network for STEM education, as well as regional and international conferences in STEM education.

Internally, at the TECH and ENG faculties at AAU, PBL research is disseminated through PhD training, pedagogical courses in collaboration with AAU Learning Lab, development projects, and ad-hoc consultancy. Finally, PBL research creates a platform for students to develop their PBL competencies in various educational programmes at TECH and ENG.

FIGURE 6.13
Overview of AALBORG PBL CENTRE’s international network, regarding project consortiums and article co-authorships



Source: AALBORG PBL CENTRE VBN

These dissemination activities, both external and internal, play an invaluable role for the Aalborg PBL Centre and serve the UNESCO goals as well as being a source of inspiration for the development of the research, as it brings researchers into close connection with educational practice – with staff from different cultures, institutions, disciplines, and not least with our students.

Besides the aforementioned activities, the Aalborg PBL Centre is also part of several international organisations and boards, namely the International Centre for Engineering Education's (ICEE) advisory board (Tsinghua University, China), the Research Engineering Education Network's (REEN) governing board, the European Journal of Engineering Education's (EJEE) editorial board; the International Journal of Sustainability in Higher Education's editorial board, the International Journal of Science and Mathematics Education's editorial board, and the Mathematical Thinking and Learning's editorial board. Along with colleagues from the other faculties at AAU, we participate in publishing in the JPBLHE (Journal of PBL in Higher Education) through the AAU PBL Academy. Furthermore, the Aalborg PBL Centre uses a newsletter and two social media platforms (Facebook and LinkedIn) to regularly disseminate and share their activities and events.

6.4 FUTURE RESEARCH STRATEGY

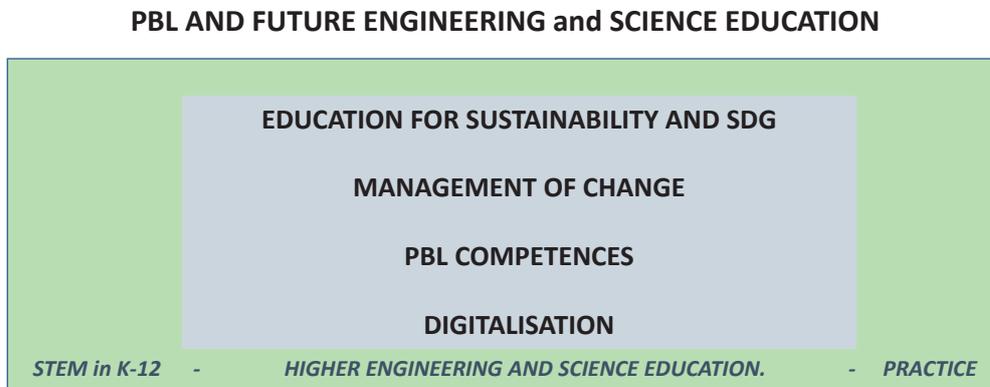
In the summer of 2019, UNESCO extended the Aalborg PBL Centre for another five year period (2020–2025) and at a research seminar of the Aalborg PBL Centre's in December 2019, the strategic focus for the coming five years was outlined based on the core themes in the PBL's research (see figure 6.14). As the Aalborg PBL Centre has been continued as a UNESCO category 2 centre until 2025, there is a need to formulate a strategy plan for both research and outreach. Basically, the main areas will be continued in the future strategy, but with an enhanced focus on sustainability, complexity and digitalisation. The research strategy, entitled *PBL and Future Engineering and Science Education*, has its core focus on the future of engineering and science education concerning types of knowledge and competencies and new PBL-blended learning models. Four topics are at the core: Education for Sustainable Development, Management of Change, PBL Competencies, and Digitalisation, which will be related to the fields of STEM education in K12, Higher Engineering, Science Education and professional practice.

Sustainability, including the SDGs, is seen as a holistic concept that includes principles, vision, ethics and values, involving more complex problem-solving and interdisciplinary approaches. Students working with SDGs need to have a solid and thorough understanding of the disciplines as well as an interdisciplinary and holistic approach to problem analysis and problem solving. To facilitate integration of the SDGs into engineering and science education, there will be a focus on:

- Identification of how the disciplines contribute to the SDGs and complex problem solving.
- Study of the perception and needs for sustainability and SDGs of students, academic staff, management and other stakeholders.
- Developing diverse resources to support students' learning for sustainability, as well as for academic staff's development and assessing their impact.
- Interdisciplinary, progressive, flexible and personalised curriculum structures that support students and academic staff in addressing sustainability and the SDGs.

Research on PBL and the management of change in engineering and science education are the core areas of the Aalborg PBL Centre. In particular, management of change has been related to sustainability, PBL competency, and digitalisation, as it will involve new implementation in curricula and often an organisational approach. Retention, assessment, comparison of the effect of various learning methodologies, staff development methods, learning environment, design of projects, and progressive PBL learning objectives are just some of the researched topics in this area. There will be *increasing research on variation in PBL models, problem types and project types to facilitate the integration of complex problem solving into the engineering and science disciplines*. This will also encompass new collaboration patterns and project management skills.

FIGURE 6.14
Overview of upcoming areas for AALBORG PBL CENTRE's research



Based on this perspective, the research strategy includes research on:

- Future engineering competencies and what future engineering students should learn.
- Curriculum change and how PBL can match various forms of learning outcomes and institutional structures.
- Variations in PBL models, problem types and project types
- Methods to facilitate staff development being aligned with the increasing complexity and diversity in PBL competencies, including different project types and problem types, new collaboration patterns, and new demands to integrate and balance current trends related to Industry 4.0 as well as sustainability.

PBL competencies refer to the fact that PBL contains learning methods for scientific content, but also creates competencies in itself. As Aalborg University has taken initiatives to formulate the PBL competencies explicitly throughout the curriculum, this provides a unique opportunity to establish frontier *research on the progression of practice-based skills and competencies in higher education*, which is still unknown territory. There will be a focus on:

- The conceptual understanding of PBL competencies, including the non-cognitive quality of PBL, for staff and students by considering the affective and emotive domain.
- Progression of PBL competencies, including action research on the AAU case.
- The dynamic of individual and team-based learning in a PBL environment, including focus areas such as motivation, diversity, resilience, self-efficacy and sense of belonging.

The use of digital tools has been an integrated part of educational practice for a long time, but recently it has had an increased focus on the interaction and potential reinforcement of emergent digital technologies. In engineering education there will be increasing use of digitalised learning of the scientific content, as well on collaboration and project management. Therefore, there will be a focus on the learning aspects of this transition – in terms of both students' learning and curricula change – as the increased use of digital tools might invite new ways of organising the curriculum.

- Digital literacy, namely digital competencies, emerging technologies, data science (e.g. in relation to ethics, sustainability);
- Digital infrastructure, namely digital tools & support, organisation and implementation;
- Digitalised learning, namely blended curriculum models, learning analytics & assessment, digital collaboration and learning communities.

Finally, in terms of local, national and international partners, the research group has created a unique research profile which adds a PBL perspective to the STEM initiatives at primary and secondary school,

as well as in vocational and higher education. This research profile with the research priorities will form the foundation of the activities which will be undertaken.

- Clarify and elaborate on the transition of pre-engineering competencies.
- Increase the attractiveness of STEM by studying what motivates pupils to pursue STEM and how a PBL approach could foster increased interest in STEM, e.g. by bringing in real-life scenarios.
- Explore the importance of tangible modalities in the ideation process of engineering and how emergent technologies can play a role in creating a pre-engineering identity.
- Clarify the needs for postgraduate engineering professional development, considering the trends of Industry 4.0 and the increasing focus on sustainable engineering.
- Explore synergies of new pedagogical structures, e.g. mega projects, social relations, partnerships and communities of practices across formal educational borders from K12 to Continuing Engineering Education.

6.4.1 Funding strategy

The centre will be funded partly by Aalborg University (primarily through internal teaching tasks centred around PBL) and partly by external sources. This is a fundamental strategy in order to make use of the established research to develop PBL internally at the university, and at the same time engage with partners to produce comparable and trans-institutional research.

At present we have many minor projects, which is partly due to the fact that many research projects are initiated by case-specific problems relevant to the key areas of research. Furthermore, as the mission of the AALBORG PBL CENTRE is also to have an impact on the transformation of engineering practice, the impact of a project on educational practice is also considered to be of high importance.

However, although the minor projects provide a diverse experience platform for the research group, the strategy is to establish more long-term and intense projects which provide more time and resources to go into depth with specific research areas and develop long-term partnerships. Considering the research on PBL and staff development (within the theme of management of change), the research group has succeeded in doing this through long-term collaborations, most recently with partners in China, India, Africa and South America.

We want to go for larger projects and to work with other research groups and engineering and science departments even more, in order to attract more funding for interdisciplinary research. There are well-established examples of such collaborations, but these examples have just confirmed that there might be considerable unexplored potential. To work towards this strategy, closer collaboration with the AAU fundraisers is expected to be beneficial.

Last but not least, activities in the global network of the AALBORG PBL CENTRE provide valuable contact with potential partners, in DK, in the Nordics and worldwide, which has resulted in cross-institutional and cross-cultural research and impact, which is and should be a premise for practising under the auspices of UNESCO.

6.4.2 Publication strategy

The PBL research group has a tradition of writing together in small teams, typically of 2–4 researchers, to combine different perspectives on PBL. Furthermore, our global network opens up opportunities for cross-institutional publications. For future work on applications, however, we see clear potential in co-writing applications with researchers from other research groups and departments at Aalborg University who are working with PBL from a disciplinary perspective. In the pipeline will be more emphasis on publishing books about new conceptual developments in complex problem-solving.

Key journal publication channels are the European Journal of Engineering Education, the International Journal of Engineering Education, the Journal of Engineering Education, the International Journal of Science and Mathematical Education, and the International Journal of Sustainability in Higher Education and Tertiary Education and Management. In the future, publication challenges are expected to be expanded due to the increased focus on STEM and digitalised learning.

6.4.3 Future outreach

Plans for future outreach strategies are under development. The International Research Symposia will be continued along with a focus on establishing more regional research symposia at PBL. In 2019, the first Regional Research Symposia was hosted by KLE-TECH, Hubli, India, and this event will be continued throughout the 20s. The strategy of building up regional networks will be applied more in the coming years, combined with the success of our free digital online resources, to support international capacity for changing education. New digital platforms for networking will also be used for the development of the global network and the development of free online resources which can be used for academic staff development.

As the Aalborg PBL Centre is a small organisation, there will be a continuous focus on collaboration with other organisations in order to increase the scope of the outreach.

6.5 OPPORTUNITIES AND CHALLENGES

With the existing funding model at AAU, one of the main challenges is that we do not have our own programme, except for the master's in PBL, which is a one-year professional master's. That means that the main income for research which comes from teaching will always be negotiable with the programmes and departments where we teach the internal PBL courses. Furthermore, our internal income for supporting centre activities is dependent on the university management's policy in relation to PBL and the approach to other strategic areas, such as the SDGs and digitalisation.

Even if the core is PBL, another challenge is that we cover a broad range of research topics, from school to university and work within both engineering and science. It is, however, important for the centre to retain a broad research profile, as problem-based learning and engineering education is not at the core of funding schemes, and a broad scope is necessary for accessing more funding opportunities and to be able to react to current needs for educational change. In most of the research areas, the primary target groups include only the public sector, and funding opportunities are quite different depending on whether the education is situated in schools or at workplaces. In summary, it is a challenge to navigate the variety of funding possibilities that, to a greater or lesser extent, can be appropriated to educational research aims.

Internationally, there has been an increasing recognition of PBL as a pedagogical response to political aims, e.g. regarding employability and sustainability. Aalborg University serves as an excellent living lab for experimenting with the newest and most advanced features of PBL, which includes research on variations of PBL models, complex problem solving, progression in PBL competencies, problem-based and digital learning modes, and education for sustainability. The research group has a strong profile in terms of conceptual and design-based research on PBL which is carried out in close interaction with everyday educational practice. Being an internationally recognised centre with partners all over the world and being situated at a systemic PBL university therefore provides brilliant opportunities for combining conceptual and change-oriented PBL research and expanding our capacity-building activities.