COMPARING TWO APPROACHES FOR ENGINEERING EDUCATION DEVELOPMENT: PBL AND CDIO

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ABSTRACT

During the last decade there have been two dominating models for reforming engineering education: Problem/Project Based Learning (PBL) and the CDIO Initiative. The aim of this paper is to compare the PBL and CDIO approaches to engineering education reform, to identify and explain similarities and differences. CDIO and PBL will each be defined and compared in terms of the original need analysis, underlying educational philosophy and the essentials of the respective approaches to engineering education. In these respects we see many similarities. Circumstances that explain differences in history and experiences will be identified and discussed. The comparison gives an overview of history and experiences, organization of community, curriculum implementation principles, model of change, variation in implementation, body of research, and extent of dissemination (world map). It is suggested that the two approaches have much in common and can be combined, and especially that the practitioners have much to learn from each other's experiences through a dialogue between the communities. This structured comparison will potentially indicate specifically what an institution experienced in one of the communities can learn from the other, as well as provide a chart for anyone who wishes to learn about any of these models. As a conclusion, some observations on common lessons learned will be made.

KEYWORDS

CDIO, problem-based learning, project-based learning

INTRODUCTION

The aim of this paper is to make a thorough description and structured comparison of Problem/Project Based Learning (PBL) and the CDIO Initiative, two approaches to engineering education development. This review is intended to provide a starting point for anyone who wishes to learn about any of these models, or both. In particular, this review can be used as a guide for an institution shaping a plan to reform their engineering education. Further, it aims to identify what kind of insights that an institution experienced in one of the communities can potentially learn from practitioners applying the other approach.

COMPARING THE STARTING POINTS

PBL – Starting Point

In the late 60’s and early 70’s, there was a period of expansion of the number of universities. Several new universities were established with new educational models. The problem-based learning model was implemented especially in health education at McMaster University (founded 1968) Maastricht (founded 1972) and Newcastle (founded 1978), and the problem and project organized/based model was practiced at Roskilde University (founded 1972) and Aalborg University (founded 1974) – in a wide range of subject areas such as engineering, science, social science, and the humanities.

The origins for PBL does not come from one source or organization, but emerge from a societal period with experimentations in the educational systems. The pedagogy behind the PBL practices that were established has developed into a sound theory of learning and is today well documented in all aspects of curriculum development, learning and competence development. Since the establishment of the PBL universities, the PBL models have been implemented all over the world. Especially the McMaster and the Maastricht models are utilized in health and law, whereas the Aalborg model with the problem based and project based/organized is most often used in variations in engineering and science.

These universities have been a type milestone for development of student centred learning models in higher education and have played an important role as documentation of alternative teaching and learning models were possible.

In the PBL curriculum, the learning outcomes address both knowledge, skills and competences and the projects are very often used as the learning platform for students to achieve competences and relate disciplines to each other in both an analysis and identification of problems as well as the problem solving process. In the PBL curriculum process skills such as self-directed learning, project management, collaboration, communication etc. are taught in an integrated way by letting the student practice and reflect upon their practice.

A PBL curriculum involves pedagogical training of academic staff to become facilitators (supervisors/advisors) of the students’ learning process. It is a fundamental principal that the students are owners of the learning process and the role of the facilitator is to guide the students by presenting several ideas, methods, and tools for the students to choose among.

CDIO – Starting Point

The starting point of CDIO was the development of the CDIO Syllabus, beginning at MIT from around the year 1998. It was intended to address the question: “*What is the full set of knowledge, skills, and attitudes that engineering students should possess as they graduate?*” The CDIO Syllabus listed and categorized desired qualities of engineering graduates, based on stakeholder input on what engineers should be able to do as professional practitioners, namely to *conceive, design, implement and operate* products and systems. This work was explicitly presented as a reaction to conventional engineering education. The observation was that engineering science was quickly replacing engineering practice as the dominant culture of engineering education institutions. Compared to a few decades earlier, much fewer faculty members had any experience of working as engineers, and values related to professional practice were quickly being lost in the university organization. Crawley summed it up straightforwardly in the Syllabus report [1]: *”Education of engineers had become disassociated from the practice of engineering”*.

The CDIO Syllabus was derived based on stakeholder input and comprehensive systematic validation. Industry feedback on requirements for engineers is cited as key references [2], [3],

[4]. The other important stakeholder requirement on learning outcomes came from the new accreditation standards in the US, which for the first time were outcomes-based and emphasizing a wider set of skills [5].

The early work at MIT struck a chord with Swedish educators and industrialists, and as a result the CDIO Initiative was formed in 1999 as a joint project by MIT and three Swedish universities: KTH Royal Institute of Technology, Chalmers, and Linköping University. The project obtained four years of funding from the Knut and Alice Wallenberg Foundation, and the four partners set out to develop pilot CDIO programs aligned with the qualities necessary for professional practice, as specified in the CDIO Syllabus.

The CDIO Initiative adopted the aim to educate students who are able to:
- Master a deeper working knowledge of technical fundamentals.
- Lead in the creation and operation of new products, processes, and systems.
- Understand the importance and strategic impact of research and technological development on society.

Soon, other institutions all over the world expressed their interest to participate in developing and implementing these ideas, and were invited to join as collaborators. To the present date the CDIO Initiative has grown to about 80 collaborators (and counting) worldwide.

Conclusion – Comparing the Starting Points

CDIO and PBL share the focus on a broader set of learning outcomes compared to traditional academic education programs, especially emphasizing student development of skills and personal development; becoming a professional. The history and starting points seem to differ slightly, however. PBL started out across disciplines and educational programs, while CDIO is focused on one professional field – engineering. Also the means and ends logic seems to differ. For PBL it was the learning process and student-centeredness that came first. The aim of CDIO is about aligning the intended learning outcomes with professional practice – and the focus on more appropriate processes for teaching and learning came as a consequence of that. This difference is consistent with the spirit of the time when respective approach was developed. In the roots of PBL the social agenda of the 60’s and 70’s is somewhat visible. The CDIO Initiative was established much later and we can trace more current trends, such as outcomes-based education (spurred on by such external forces as ABET and the Bologna process) and, perhaps more generally, how external stakeholder demand is challenging a “pure” academic culture.

COMPARING THE ESSENTIALS

PBL – Extracting the Essentials

Since the first establishment of the problem-based and/or project-based learning in the pioneering institutions, many other existing universities have since adapted or partially adopted the problem-based model [6], [7] leading to a wide variety of implementations worldwide. PBL is applied in many different cultural settings, subject areas and at different different levels in the educational system. The scope of implementation ranges from institutional, program and course level. Perhaps due to this diversity, there is a continuing debate about what counts as problem-based learning and what does not [8].

The UNESCO Chair in Problem Based Learning in Engineering Education (UCPBL) recognizes these multicultural differences and has developed an understanding of PBL based on the diverse practices, in order to create a PBL global network as a global community. The PBL learning principles formulated here are intended to form a broad platform and include both the McMaster/Maastricht model and the Aalborg model. The common platform for these two models is the problem orientation and the fact that the learning starts by analyzing and defining problems. These problems can be more open and ill defined or they can be well defined. The design of the problems depend on the learning outcomes – if the learning outcomes are to achieve learning of methodologies it will require open problems, if the learning outcomes are to achieve specific methods more narrow problems will be suitable. However, some differences are seen, especially concerning the learning process. In the Maastricht model students are analyzing cases and learn how to organize the learning process by seven steps procedures, whereas in the Aalborg model students work collaborative in teams on projects and have to learn project management skills that can be transferred from one project to the other. The process for Maastricht students seem to be more structured from the very beginning whereas the collaborative and knowledge construction seem to be more basic in the Aalborg model. Finally, the assessment systems are different, both the formative system as well as the assessment methods. However, the learning principles formulated for these two different models are more or less the same.

Barrows [9] stressed these elements as part of problem-based learning:

- the use of problems as a starting point for the acquisition and integration of new knowledge,
- that new information is acquired through self-directed learning,
- that it is student-centred,
- the use of small student groups, and
- teachers in the role of facilitators and guides.

Nearly the same elements were originally formulated in Denmark by Illeris [10] beyond the problem-based and project-based models, namely problem orientation, interdisciplinary learning, exemplarity towards overall educational objectives and teamwork.

Along with a widespread use of PBL, various practices and models have occurred. The specific understanding of the PBL concept has also become more diverse and Graaff and Kolmos [7, 11] argue that there will always be variations in the models used. Especially, when utilizing PBL in various educational systems that represent a wide range of cultures, the very concrete models will and must be different. Therefore, it might be problematic to define educational concepts by the concrete elements, but they have to be defined by the learning principles and pedagogy beyond the concrete practice. Graaff and Kolmos [7, 11] therefore argue for a set of learning principles that derive from the concrete models and are reflected in the learning theories [12,13,14] and summarize the main learning principles in three approaches: cognitive learning, contents and collaborative learning.

The cognitive learning approach means that learning is organized around problems and will be carried out in projects. It is a central principle for the development of motivation. A problem makes the starting point for the learning processes, places learning in context, and bases learning on the learner's experience. The fact that it is also project-based means that it is a unique task involving more complex and situated problem analyses and problem solving strategies – this condition is only valid for problem based and project based learning.

The content approach especially concerns interdisciplinary learning, which may span across traditional subject-related boundaries and methods. It is exemplary practice in the sense that learning outcome is exemplary to the overall objectives and supports the relation between theory and practice by the fact that the learning process involves an analytical approach using theory in the analysis of problems and problem solving methods.

The social approach is team-based learning. The team learning aspect underpins the learning process as a social act where learning takes place through dialogue and communication. Furthermore, the students are not only learning from each other, but they also learn to share knowledge and organize the process of collaborative learning. The social approach also covers the concept of participant-directed learning, which indicates a collective ownership of the learning process and, especially, the formulation of the problem.

These three principles can be regarded as essential, so that any claim to run PBL should mean that the practice reflects all learning principles – not only one or two of them. Programs that claim running PBL because of *individual* capstone projects are not PBL according to this approach – there must be a team aspect and there must be a certain freedom for the students to choose problems that they want to work on.

CDIO - Extracting the Essentials

Soon in the history of the CDIO Initiative came the need to be able to distinguish a CDIO program from any other program. As the number of collaborators grew, it was necessary to accommodate a wider diversity of implementations, in a wide range of programs and institutions. But the sense was that the dialogue with stakeholders needed some level of clarity about what counts as a CDIO program. There was a risk that the concept could be watered down if “anything goes”.

While the CDIO Syllabus addresses *what* the students should be able to do upon graduation, it was not intended to be prescriptive. That is, to be recognized as a CDIO program it does not need to include all the learning outcomes from the CDIO Syllabus, and any other learning outcomes can be added as deemed appropriate in dialogue with stakeholders. The Syllabus document is to be seen as an instrument to support programs in the process of specifying its own goals, and formulating the intended learning outcomes considering all local needs and conditions: the national context, stakeholder needs, institution, level and scope of programs, subject area, etc. Had the CDIO Syllabus been prescriptive, the Initiative would not be able to accommodate diversity in any of these dimensions. Thus the use of the CDIO Syllabus cannot be an essential element of a CDIO program.

What instead did become the distinguishing feature, was *how to run the process of educational reform;* the CDIO approach itself. The CDIO Syllabus lists desired learning outcomes - addressing the question of *what* graduates should be able to do. Naturally, the question that immediately follows is the *how* question: “*How can we do better at ensuring that students learn these skills?*” In 2006, the process of engineering education development was captured in the twelve CDIO Standards (see table 1). This is the working definition of CDIO [15].

Table 1
The CDIO Standards

Standard 1 – The Context *   *Adoption of the principle that product, process, and system lifecycle development and deployment – Conceiving, Designing, Implementing and Operating – are the context for engineering education.*
Standard 2 – Learning Outcomes *   *Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders.*
Standard 3 – Integrated Curriculum *   *A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills*
Standard 4 – Introduction to Engineering   *An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills.*

Standard 5 – Design-Implement Experiences *   *A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level.*
Standard 6 – Engineering Workspaces   *Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning.*
Standard 7 – Integrated Learning Experiences *   *Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills*.
Standard 8 – Active Learning   *Teaching and learning based on active experiential learning methods*.
Standard 9 – Enhancement of Faculty Competence *   *Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills*.
Standard 10 – Enhancement of Faculty Teaching Competence   *Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning*.
Standard 11 – Learning Assessment *   *Assessment of student learning in personal and interpersonal skills, and product, process and system building skills, as well as in disciplinary knowledge.*
Standard 12 – Program Evaluation *A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement.*

Of the twelve Standards, seven (marked with asterisks in table 1) are considered to be essential. Together the essential standards prescribe a minimal approach for developing a CDIO program, starting with the recognition that education aims at preparing for *engineering practice* – in other words for conceiving, designing, implementing and operating products, processes and systems (Standard 1); the formulation of intended *learning outcomes*, including both disciplinary knowledge and the skills necessary for professional practice, in dialogue with stakeholders (Standard 2); designing a *curriculum* consisting of *courses* where student development of professional engineering skills is *integrated* with discipline-led learning, and both these aspects are *assessed* (Standard 3, 7 and 11); including at least two learning experiences where students *design, implement and test* a product, process or system (Standard 5).

The CDIO Standards can be seen as recommended areas for improvement of engineering education, a set of principles for bringing about change in a systematic way. The main value lies not in any of the standards alone, but in putting them all together, creating a comprehensive approach. For many program managers, the standards represent a roadmap, a useful to-do list of different drivers available to them. The CDIO Standards document has been equipped with rubrics for rating a program in these twelve dimensions [16]. An alternative way to use the standards is thus as a basis for evaluation [17].

Conclusion – Comparing the Essentials

Perhaps the most obvious difference between CDIO and PBL is the degree to which their essentials can be the subject of any definition at all. The principles for PBL recommended here as essential are certainly known to be conducive to learning; they are evidence-based. However, a multitude of definitions exist for PBL, and there is arguably no single forum where such consensus could be established. On the other hand, there is a formal and codified definition of CDIO, the CDIO Standards, formulated and controlled by the CDIO Initiative.

Another notable difference is the nature of what these working definitions set out to define. The three PBL principles proposed here concern the nature of the teaching and learning process; they broadly define a pedagogical approach, which can be used on course, program or institutional level. The CDIO Standards, on the other hand, define a highly structured outcomes-based approach to development of engineering *programs*, a roadmap for change from a program perspective. Implicit in the Standards, however, is also a pedagogical model for the education itself, containing elements of PBL but also stressing the valuable contributions from well-designed disciplinary courses.

A consequence is that PBL is obviously applicable to all different types of education, on all levels, because it is exclusively oriented to the learning *process*, that is, more focused on *how* students should learn, and less with *what* they should learn. CDIO is designed specifically for engineering education, and it is explicitly outcomes-based – *how* student learning should be facilitated is mainly a consequence of *what* they should learn, the desired learning outcomes. CDIO as an approach to educational development could serve as an inspiration for outcomes-based development of other professional education, for instance in health or education, after adaptation to the desired outcomes of the specific field.

COMPARING THE CURRICULUM MODELS

PBL – Curriculum Models

Kolmos and Graaff [7] have defined a set of elements for development of a PBL curriculum: objectives, types of problems and projects, progression, students' learning, academic staff, space and organization, and finally assessment. Basically, there are two extremes in the interpretation and implementation of the curriculum elements: a discipline and teacher-controlled approach on the one side and an innovative and learner-centered approach on the other side. In between the two approaches there are mixed modes, and most of the PBL practice is defined as some kind of mix mode. In each of the curriculum elements there are several dimensions as illustrated in table 2.

Table 2
Dimensions of PBL curriculum elements [18]

Curriculum element	**Discipline and teacher controlled approach**	**Innovative and learner-centred approach**
Objectives and knowledge	Traditional discipline objectives Disciplinary knowledge	PBL and methodological objectives Interdisciplinary knowledge
Type of problems and projects	Narrow Well defined problems Disciplined projects Study projects Lectures determine the project	Open Ill defined problems Problem projects Innovation projects Lectures support the project
Progression, size and duration	No visible progression Minor part of the curriculum	Visible and clear progression Major part of course/curriculum
Students' learning	Acquisition of knowledge	Construction of knowledge
Academic staff and facilitation	No training Teacher-controlled supervision	Training courses Facilitator/ process guide
Space and organization	Administration from traditional course and lecture-based curriculum	Administration supports PBL curriculum

	Traditional library structure Lecture rooms	Library to support PBL Physical space to facilitate teamwork
Assessment and evaluation	Individual assessment Summative course evaluation	Group assessment Formative evaluation

This model is meant for designing a curriculum, where it is possible to scale each dimension and where it is important to design the specific curriculum according to the intended learning outcomes. In Table 2 it is the poles that are illustrated, but there might be many mixed modes. For example, concerning the assessment system, there are many ways of practicing assessment to support the learning objectives such as peer assessment, formative assessment etc. So the point in formulating the poles is to create awareness in the implementation process of PBL – regardless whether this is at a system level or at a single course level.

An example is the Aalborg PBL model, which is one of the most complete implementations of PBL at a system level, see figure 1. Here, the proportion of courses is 50/50 and the disciplines are basically taught in the courses. The relation between the courses and the projects vary from one semester to the other semester depending on the intended learning outcomes. At some semesters the students apply elements of the courses in the project in order to achieve a competence level, in other semesters the project is independent of the disciplines in the courses and has its own learning outcomes and the students use their learning from the courses if it is adequate for the project.

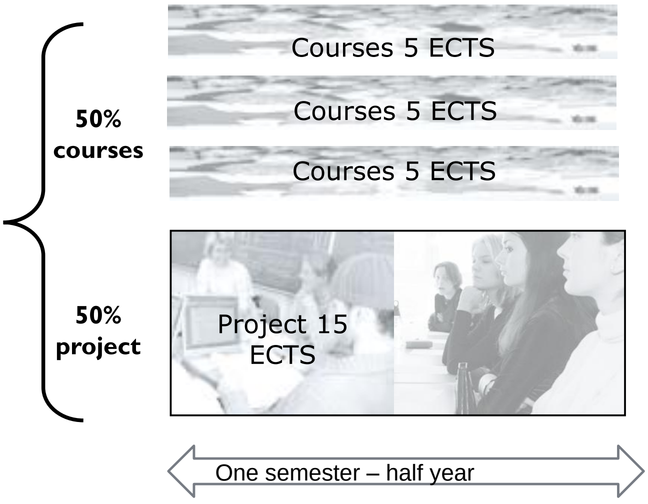

Figure 1. The Aalborg Curriculum Model

CDIO – Curriculum Model

CDIO – Combining the Values of Discipline-led and Problem/Project-led Learning

Educational development in the CDIO Initiative has focused on designing and implementing curricula to support student development of professional skills, their understanding of engineering work processes and their ability to work and collaborate in engineering organizations. To accommodate the nature of these learning outcomes, it is necessary in most programs to *increase the share* of problem-based and project-organized learning activities. In CDIO, this is most notably achieved through the introduction of so called Design-

Implement Experiences within the programs, and through application of many other active and experiential learning methods in the integrated curriculum.

Educating for the context of professional practice has not however led the CDIO community to the conclusion that the format of the education should necessarily be fully problem/project-based. Discipline-led learning takes a highly prominent place in CDIO, and indeed, the first aim is a deeper working understanding of disciplinary fundamentals – because this too is a necessary basis for professional practice, for problem solving and innovation. Provided that the discipline-led courses work well, they can provide the important value of a systematic treatment of a body of knowledge. Therefore, the improvement of student learning in mutually supporting discipline-based courses has been an important focus in CDIO. Table 3 lists some of the values from discipline-led and problem/practice-led learning in the integrated curriculum.

Table 3
Contributions of Discipline-led and Problem/practice-led Learning
in the Integrated Curriculum

Discipline-led learning	**Problem/practice-led learning**
contributes: ▪ A well-structured knowledge base (”content”), ▪ Knowing what is known and what is not, evidence/theory, model/reality, ▪ Methods to further the knowledge frontier, scientific process skills, ▪ Interconnecting the disciplines, *and the discipline-led learning must support problem/practice-led learning through:* ▪ Orientation towards use, a working understanding, ▪ Seeing the disciplinary knowledge through the lenses of problems, ▪ Embedded development of skills such as communication and collaboration skills.	*contributes*: ▪ Integration, application, synthesis of knowledge ▪ Working with open-ended problems, ambiguity, trade-offs, conditions of specific contexts, conflicting interests ▪ Professional skills (work processes, habits) ▪ Conceive, design, implement and operate solutions, or ”*create the world that never has been*” (Theodore von Kármán) ▪ Knowledge building of the practice *and the problem/practice-based learning must support discipline-led learning through:* ▪ Drawing on the disciplinary knowledge ▪ Reinforcing disciplinary understanding ▪ Creating a motivational context for learning the fundamentals

It is obvious that engineering graduates need both these types of learning outcomes, and therefore both approaches are necessary. To combine the values of problem-led and discipline-led learning, effectiveness lies in designing and implementing a curriculum where the approaches are mutually supporting, using resources efficiently. Through *the integrated curriculum*, the CDIO Initiative has actively strived to reconcile the either/or (and zero-sum) thinking in the debate about discipline-led and problem/practice-led learning. The aim is to combine these two modes of learning in a way that they give each other meaning, in order to address the full set of learning outcomes of an engineering program.

Designing the Integrated Curriculum; Integrated Learning Experiences

The process described by the CDIO Standards is a top-down structured approach to curriculum development. In a nutshell, the starting point is to establish a vision of the graduates, based on the analysis of stakeholder needs, the context and conditions. These high-level goals are translated into program learning outcomes, containing explicit learning outcomes for professional skills, as well as disciplinary knowledge, and validated by program stakeholders. Then, a curriculum structure is designed, taking interdisciplinary connections into consideration, and systematically and explicitly the contribution of each course is negotiated. The “currency” for this negotiation is the course level learning outcomes. Thus, each course has an explicit function in the program, and its intended learning outcomes can be explicitly traced back to the program level learning outcomes.

Finally, the courses are designed as *integrated learning experiences* leading to the simultaneous acquisition of disciplinary knowledge and professional skills. The pedagogical principle is that since the intended learning outcomes for the course address both disciplinary knowledge and professional skills, this should be reflected also in the nature of learning activities and in the assessment system.

Conclusion – Comparing the Curriculum Models

For PBL, there is a wide diversity in the level of implementation for PBL, from a single learning activity to a program, to across whole institutions. CDIO, on the other hand, is decidedly a concept exclusively for the program level. It is not applicable to say that a single course in a program is a CDIO course. But while CDIO essentially *is* a model for curriculum development, it is not so straightforward to say that PBL implies a curriculum model. Research evidence [19] suggests that PBL works best when it is implemented consistently across the curriculum, and institutional support systems, buildings (etc) are aligned with the educational model, but it is also possible to argue that it is better for the students to have a few instances of PBL in their education than none at all.

COMPARING THE COMMUNITIES

PBL – Communities

It is more correct to discuss PBL communities in plural, as there are several. Among the most established ones are:

- The UNESCO Chair in Problem Based Learning in Engineering Education, runs the PBL Global Network running research symposia every second year.
- The International PBL Symposium is organized by Republic Polytechnic, Singapore, runs an international symposium every second year, and works as the hub of an Asian community.
- Pan-American Network for Problem-based Learning, runs international conferences each second year.

Compared to other PBL communities the UCPBL has a declared a strong emphasis on research and is running research symposia every second year and is based on philosophy and learning principles across different PBL practices (Maastricht and Aalborg), derived from educational research and practice.

The PBL curriculum models have been well researched and documented and the research indicates that industry and companies rank PBL universities highly and that the graduates are able to work from day one in the workplace. There is documentation that students graduated from a PBL program achieve a higher level of skills and competences, deeper learning, increase motivation, and compared to other traditional universities the PBL programs increase retention rates, students even get higher grades and higher salary.

There is plenty of literature reviews on PBL and research indicating the success of PBL. However, there is also literature indicating the risks such as lack of proportional discipline knowledge. But it is important to emphasize that there is no institution that only practices PBL, but there are mostly hybrid models of traditional taught courses and PBL. Even Aalborg University is a hybrid model in the sense that the students attend courses half their study time.

CDIO – Community

The CDIO Initiative grew out of the joint activities of the four founding member institutions, and new collaborators began to join from around 2002. The CDIO Council was established consisting of representatives of the founding institutions and the first six collaborators to join. This governing structure is now in the process of being replaced with a more democratic organization, to better reflect and serve the current community of collaborators and activities. There is a simple but formal procedure to become a CDIO Collaborator – a request is made to the CDIO Council, which grants collaborator status. To date there are about 80 CDIO collaborators worldwide in all parts of the world. The CDIO Council also controls the defining documents of CDIO, the CDIO Syllabus and the CDIO Standards.

Starting in 2005, the CDIO Initiative has met in its Annual International Conference (June) and the smaller Worldwide CDIO Meeting (October/November). These meetings are open not only to formal collaborators, but to anyone interested in engineering education. A large number of conference papers have been published in the proceedings of the annual conferences. Further, a book on the CDIO approach was written by the early collaborators, published in 2007 [15], with a new edition currently in the process. The website of the CDIO Initiative [20] contains resources and contacts as a starting point for anyone interested in the ideas and the community.

Most CDIO publications can arguably be characterized by a focus on sharing the practices of engineering education development. This is a natural implication of the fact that the initiative consists mainly of engineering faculty documenting the endeavor of reforming the education. CDIO is first and foremost an effort to reform engineering education. Any publications or career progression has been seen as a by-product of the educational development itself, or from the lessons learned in this practice. Of course, some work and several publications can be categorized as educational research, often due to the ambition of the individual contributors, in some rare cases coinciding with a position as educational researcher.

Conclusion – Comparing the Communities

The natures of the CDIO and PBL communities are very different. The CDIO Initiative is a relatively well-defined and controlled organization; the PBL community, with its much longer history, is rather like a cluster of communities of practice. As for any educational development community, there are tensions between a precisely defined and centralized model, and an inclusive and decentralized model. In table 4, some trade-offs are identified, based on our experience in these communities.

Table 4
Trade-offs: Considerations on Inclusivity/Exclusivity
for Educational Development Communities

	Inclusive and decentralized control	**Exclusive and centralized control**
Entering the community	Easy to join the community and start implementing. Continuous influx of new people and ideas.	Higher entry threshold for new implementers. Closed community.
Potential reach	Diverse implementations necessary for models to work in a diversity of contexts.	Lower adaptability to different contexts and conditions, risk of rigid implementations.

Evidence	More context-dependent?	More generalizable?
Status	Risk of ”anything goes” and ”trademark infringement”. Lack of stimulus for excellence.	Status attached to exclusivity of label and to being and staying ”in”.
Central organization	Less control - less administrative work to manage it. Lack of legitimacy for central initiatives within the community.	Firmer control must be managed – means work and organization, cost and potential conflict.
Institutional commitment	Less institutional agreement required for joining. Creates opportunities also for progressive individuals with limited institutional support.	High level of control required within institution to join – can be a guarantee for institutional support.

COMPARING THE STRATEGIES FOR LEGITIMACY

PBL – Strategies for Legitimacy

Organizing learning around problems and stressing interdisciplinary learning makes PBL often perceived as challenging the traditions, and through its history it certainly has provoked substantial resistance in institutions. As a consequence, the change management perspective has become an important part of discussions [11]. It is no coincidence that some of the most sustainable implementations of PBL were created when new universities were started around these principles. An important legitimizing strategy has been to provide the research evidence for the effect of PBL (as discussed above), as in the absence of evidence it is difficult to defend investment of resources in any change.

CDIO – Strategies for Legitimacy

Within the CDIO community there is strong critique against poorly designed “stovepipe” curricula, consisting of isolated disciplinary courses, too often loosely coupled to program goals, professional practice and student motivation. However, the response in CDIO was not to overturn the discipline-organized curriculum to any great extent, but to re-task and improve the disciplinary courses, so they contribute to the desired learning outcomes relevant for engineering practice. Thus, CDIO as a model does not fundamentally challenge the role of disciplines, but rather invites rich contributions from them, to achieve the educational values associated with the discipline-led learning. It is also possible to interpret this strategy as a pragmatic approach to the implementation of educational change in in existing universities and existing programs, and a way to gain legitimacy [21] in the culture of discipline-organized academic institutions.

Another legitimizing strategy that the CDIO model is fundamentally based on is to open up channels of communication with stakeholders other than just the academic disciplines. This dialogue can help establish ways for the disciplines to align their contributions in education to high-level goals, validated with students, employers, and society. Some of the arguments that can be heard in internal curriculum discussions are quickly exposed as self-serving or sub-optimizing, in the light of these high-level goals.

Conclusion – Comparing the Strategies for Legitimacy

While problem-led learning aims to be aligned with professional practice, discipline-led learning is more aligned with the way most institutions are organized. For some reason, it seems that the discipline-based organization is norm not only for research-led universities, but there seems to be a strong isomorphism also in other types of institutions. Therefore, problem-led learning will *by its nature* go against the grain of the organizational principles in most institutions. In PBL, and to some extent in CDIO, we are trying to establish educational principles that partly challenge some existing traditions, taken-for-granted structures, and – not least – professional identities. While evidence of effectiveness is seldom demanded from existing structures, a burden of proof rests on those who want to introduce any change. Therefore, in both PBL and CDIO communities, strategies for making change legitimate, and thus possible, have been in the foreground.

FINAL COMMENTS

To sum up, it is apparent that the two approaches for reforming engineering education share common values and goals. The two communities also have many issues in common, and would benefit from closer interactions and exchange of experiences. One such area of mutual interest arises from the fact that CDIO and PBL are partly overlapping, as CDIO applies elements of PBL pedagogy. It is highly likely that practitioners of PBL and of the Design-Implement Experiences should find much in common. Another obvious mutual interest is the organizational change. CDIO is defined around the change process, and also in the PBL community the experiences have led to many lessons learned around change management. A third area of mutual interest and collaboration is the emerging field of engineering education research. Our first conclusion is thus that the PBL and CDIO practitioners have much to learn from each other's experiences through a dialogue between the communities.

Our second conclusion is that CDIO and PBL can be productively combined. There is no need to make a choice between the two approaches, for an institution that plans to create an innovative engineering curriculum equipping the graduates for engineering practice, problem solving and innovation,. They are not mutually exclusive, but instead they complement each other quite well. The CDIO approach supports a structured process of setting the high-level learning outcomes and systematically translating them into a curriculum, and any combination of CDIO and PBL pedagogy will help the implementation of appropriate learning experiences. Our final conclusion is that the approaches should be seen as compatible and mutually reinforcing.

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