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Characteristics of Problem-Based Learning*

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Problem-based learning (PBL) is widely regarded as a successful and innovative method for engineering education. Since the development of the PBL model at McMaster University in Canada in the late 1960s, many different varieties have emerged. This paper highlights the Dutch approach of directing the learning process through problem analysis and the Danish model of project-organised learning. Various definitions of the concept PBL identify characteristics at the levels of theoretical learning principles, educational models and educational practices. The McMaster–Maastricht PBL model and the Aalborg model of project work share characteristic features such as the theoretical principle of the problem analysis at the basis of the learning process, integration of knowledge and practice, collaboration and group work. Notable differences were found with respect to the type of assignments, assessment methods and organisation of the group work. In comparison to traditional engineering curricula, the PBL models appear to inspire a higher degree of involvement in study activities and, consequently, a higher level of complex comprehension. A possible drawback is the risk of gaps in specific knowledge areas. Therefore, it is crucial that the students in a PBL curriculum become lifelong learners who have learned to take responsibility for their own learning process.

INTRODUCTION

TYPE THE WORDS 'problem-based learning' or the letters 'PBL' into any search engine and you will find hundreds of sites dedicated to this educational method. The online database of PROBLARC in Australia contains more than 12,000 references to articles on PBL. Evidently, problem-based learning now has enormous popularity all over the world. At the same time, there is a considerable lack of clarity regarding the concept of problem-based learning. As even superficial inspection of a few of the available sources can reveal, the label 'PBL' is used to cover an amazing diversity of educational practices, ranging from problem-oriented lectures to completely open experiential learning environments aimed at improving interpersonal relations. Without challenging any of such claims to problem-based learning, the objective of this article is to identify the essential characteristics which explain the success of PBL. Within the context of a model of problem-based learning which was developed at McMaster University in Canada, we will focus in particular on the Dutch approach of directing the learning process through problem analysis and the Danish model of project-organised learning.

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PBL AS THEORY, MODEL AND PRACTICE

Many attempts have been made to define the concept 'problem-based learning'. Howard Barrows, who was involved in the early stages of the development of PBL at McMaster University in Canada, defines the concept in terms of specific attributes as being student-centred, taking place in small groups with the teacher acting as a facilitator, and being organised around problems. [1]. However, the actual design will be very different from institution to institution [2–5]. Gijselaers [6] defines PBL in relation to theoretical learning principles, such as learning as the construction of knowledge, meta-learning and contextual learning. Savin-Baden describes five different models of PBL resting on five different views of the objective of PBL, including the perception of knowledge, learning, problems, students, teacher roles, and assessment. Savin-Baden refers to these five PBL models as: attainment of knowledge, PBL for professional work, PBL for interdisciplinary comprehension, PBL for cross-discipline learning and PBL for critical competence [7].

In the various definitions of PBL, the following three levels can be distinguished:

- central theoretical learning principles;
- specific educational models based on PBL principles; and
- different practices within the guidelines of traditional educational models.

PBL, therefore, refers to theory, models, and practice. To further complicate this matter, PBL has been developed first and foremost on the basis of practice. This is in spite of the fact that there were many theoretical considerations behind the establishment of PBL models such as those practised at the universities of Linköping, Maastricht, Roskilde and Aalborg. The development of PBL through the 1970s and 1980s has been characterised by small adjustments for pragmatic reasons. Teachers have developed their own routines and, if something does not work, they have simply changed it.

The theoretical roots of PBL began to receive serious consideration in the 1990's. In Denmark, the PBL tradition builds on the experiential learning that was more or less formulated by Dewey, along with Negt/Kluge's theories of the development of work education and the development of political consciousness formulated at the beginning of the 1970's. More recently, researchers have related PBL concepts to a variety of theoretical notions, such as experiential learning (Kolb), the reflective practitioner (Schön) constructivism and social learning (Piaget, Vygotsky, Lave and Wenger) [6, 8, 9, 10]. The following are typical theoretical learning principles mentioned by these writers on PBL:

- *Problem-based learning* is an educational approach whereby the problem is the starting-point of the learning process. The type of problem is dependent on the specific organisation. Usually, the problems are based on real-life problems which have been selected and edited to meet educational objectives and criteria. However, it could also be a hypothetical problem. It is crucial that the problem serves as the basis for the learning process, because this determines the direction of the learning process and places emphasis on the formulation of a question rather than on the answer. This also allows the learning content to be related to the context, which promotes student motivation and comprehension. It is essential that the directing force is consistent with the way the assessment drives the educational method [11].
- Who formulates the problem statement and who is responsible for the main decisions is dependent on the next principle, *participant-directed learning processes*, or 'self-directed learning', which has a far more individual-oriented focus. In the vast majority of cases, students have the opportunity to determine their own problem formulation within the given subject area guidelines. In other cases, the teacher defines the problem and the student uses this as a starting-point.
- *Experience learning* is also an implicit part of the participant-directed learning process, where the student builds from his/her own experiences and interests. To link the formulation of the problem to the individual's world of experience increases motivation, because it relates to the opinions and understandings previously formed by the student.
- *Activity-based learning* is a central part of the PBL learning process, requiring activities involving research, decision-making and writing. This can motivate and give the student the opportunity to acquire deeper learning.
- *Inter-disciplinary learning* relates to problem orientation and participant-directed processes, in that the solution of the problem can extend beyond traditional subject-related boundaries and methods. This principle is critical for organising the teaching, so that teachers do not just consider objectives within the known subject-oriented framework, but also consider problems or real situations.
- *Exemplary practice* is concerned with ensuring that the benefits derived by the student are exemplary in terms of the objectives. This is a central principle, as the student must gain a deeper understanding of the selected complex problem. However, there is an inherent risk with PBL that a sufficiently broad overview of the subject area is not provided. The students must therefore acquire the ability to transfer knowledge, theory, and methods from previously learned areas to new ones.
- *Group-based learning* is the last principle, whereby the majority of the learning process takes place in groups or teams. Personal competencies are thereby developed, so that students learn to handle the process of group co-operation in all its stages [12].

The above principles are drawn from various learning theories, and, from an abstract theoretical perspective, act as a 'point of reference' for designing the specific course. The principles cover traditional PBL models as they are practised at the universities in Maastricht and Linköping, but they also cover the project models as they are practised in Aalborg and Roskilde.

EDUCATIONAL MODELS

The didactical principles of PBL encompass all curriculum development elements: objectives, teacher and student learning strategies, choice of content, learning methods, ICT, teachers' roles, organisation, culture and assessment. Changes in one of the elements involves changes in all the other elements [13]. It is not enough to change the educational framework of ordinary class teaching if, for example, changes are not also made in the format of the exams or the principles of material selection. In this way, the model represents a coherent structural practice.

Problem-based learning as a model

The PBL models, as they are practised at the universities in Maastricht, Linköping, McMaster (Ontario) and Newcastle (Australia), share a

number of characteristics [14–15], of which we have singled out the following:

- Curriculum structure

The curriculum is structured in thematic blocks, in which the semester is divided into a series of periods of approximately six weeks, and each period focuses on a particular theme. A series of cases are planned for the students to work on in each period. The students themselves choose to analyse one of the cases, which in turn can be done both orally and in writing.

The subject disciplines are integrated through relating the case to professional practice. For example, in the field of medicine, the starting-point is often a description of the patient. In Maastricht, the 'Seven Step' method was developed to help students analyse the problem:

1. clarify the concepts;
2. define the problem;
3. analyse the problem;
4. find the explanation;
5. formulate the learning objective;
6. search for further information; and
7. report and test new information.

- The learning process

Self-directed study groups discuss and analyse selected cases. The typical study group (8–12 students) meets once or twice a week. Each individual student in the study group presents his/her work. It is then discussed and the group decides who will continue with what tasks. Often students organise their work in such a way that their individual work supplements the work of the group, enabling them to develop a broader perspective of the related themes [1].

The role of the teacher who attends the meetings is primarily to facilitate the learning process (i.e. to facilitate the group's work and internal communication).

- Assessment

The assessment methods must be compatible with the objectives of the learning process. With PBL this means progress testing to establish the individual's knowledge and testing for competence rather than for isolated factual knowledge [11]. Different PBL models organise the didactic elements quite differently, allowing for variation within the general framework. However, there are limits to this flexibility. It is, for instance, not enough to simply change the educational format within the framework of ordinary class teaching. This is one of the classic 'mistakes' made when changing to PBL. Changes in the educational format must be consistent with the form of the examinations or with the principles of material selection. Otherwise, the students will soon figure out the 'examination code' and single that out as a learning goal instead of completing the PBL process [16].

Project-organised learning as a model

Project work is problem-based by definition. In identifying how to reach the project goal, the members of a team have to learn to co-operate effectively. This creates good conditions for learning, as it involves both individual and co-operative activities, interactive discussions and a writing process (mostly in the form of a project report). Project work teaches competencies such as project management and co-operation. Project assignments are also highly challenging. The more the task reflects reality, the more the students feel motivated, so working on a project can be seen as a way of organising various simultaneous and/or integrated learning processes.

The original idea of using project work as a teaching method has been attributed to the American author William Killpatrick [17]. In Denmark, this educational model gained popularity in the 1970s, when it was established and developed at Roskilde University and Aalborg University. The extent of the project work can vary. At Aalborg University, project work accounts for 50% of the students' time, but many other institutions only allocate around 20% of the students' time to project work. The main characteristic of project work is that the students write together and are assessed together in groups.

The extent of the students' involvement will determine the project's broadness and complexity. The broader and more complex the project is, the more students will be challenged to spend time on it. In addition, the more complex the project is, the broader the approach to the project needs to be, and this is directly related to the degree of freedom students have to find alternative solutions [18]. The opportunity for students to make critical choices is a prerequisite to gaining ownership of the project, and this is an important motivational factor.

Group co-operation can be difficult, and it is one of the elements that students find most difficult in the first years [19]. One of the major findings in a study on the progression of process competencies [12, 20] suggests that developing the ability to work co-operatively involves a number of skills, such as dealing with problems within one discipline, the ability to show understanding and respect for one another, reflection on personal development, and communication and listening skills. Students' personal skills develop and, in particular, their skills in co-operation and project management increase.

Types of projects

The basis for the organisation of the project work lies in the subject-oriented nature of the process, where learning objectives related to subject matter exist that must be satisfied within an educational programme. The experiences, interests and guidelines for participant-directed projects do not necessarily meet these objectives, and the typical 'why-why' approach to problem

formulation goes beyond the specified subject area within technical educational programmes. This means that the degree of 'freedom' to choose the problem is also very dependent on didactic considerations in that subject. On the other hand, some considerations are related to learning, where the students' motivation is dependent on the degree of participation—the more decisions the students are able to make, the greater their motivation. [21]. Even though there are specific learning objectives, the student must have enough freedom to get the maximum enjoyment from the work. This is a very central didactic consideration.

The degree of teacher-centred planning and direction of the student's learning activities in relation to the desired objective varies along a sliding scale. Three fundamental types of project work can be distinguished: the task project, the discipline project, and the problem project [22].

The *task project* is characterised by a very high degree of planning and direction on the part of the teacher (teaching objectives) involving a large task that has to be solved. Both the problem and the subject-oriented methods are chosen in advance, so that, for the student, the primary concern is to complete the project according to the guidelines provided. At times there can be such a narrow framework that students do not have the opportunity to make their mark on the starting-point or the process, but instead follow a strictly directed process in which the choices are made for them in advance. This is especially unfortunate, given that the defining factor for student motivation is that they should feel that the project belongs to them (and not the teacher). Therefore, this type of project cannot be recommended.

The *discipline project* is usually, though not necessarily, characterised by a fairly high degree of direction from the teacher (study programme requirements), in that the disciplines and the methods are chosen in advance. It may, however, still allow the groups to identify and define the problem within the guidelines of the described disciplines (which are described in the theme descriptions). Metaphorically, this type of project can be compared to a football game in which the playing field is specified. Similarly, some overriding guidelines are given for the game, but the ball has not been kicked off and thus the group must enter the field and set the game into play.

The *problem project* is a full-scale project in which the course of action is not planned in detail by the teachers. The problem formulation directs the choice of disciplines and methods and the problem itself arises from the problem-oriented theme. In other words, within the same work environment theme, the group can actually work with widely different disciplines and subject methods. In terms of the analogy of a football game, this means that the students have the ball but lack the playing regulations and a marked playing field. A considerable amount of the work therefore involves marking the field and defining the playing rules, before the game can be started.

PBL AND OBJECTIVES

PBL education is based on the students' background, expectations, and interests. It is a very common experience that students are more motivated and work much harder with the PBL model than with traditional teaching methods. They also spend a great deal of time on PBL work.

There is a connection between the teaching method and the depth and complexity of the learning, as the student may be expected to reach a level of analytically complex comprehension through the problem-based work that would not be possible in conventional classes. However, while students can be expected to reach this deep level of learning, it is still possible that they may miss parts of the broader perspective or breadth of knowledge. It is therefore an important part of PBL pedagogy to ensure that the student is in a position to fill in any potential 'subject area gaps', if or when there is a need for that at a later point [15].

Over the years, this has come to be described as exemplary practice or methodological cognisance (awareness). Many of the introductory books to problem-based learning, especially those on project work, outline this methodological part of the project. However, only a few attempt to grasp the issue of problem formulation: how the student and the teacher handle the process of transferring methodological experiences from one problem area to another. Experiences gathered from teachers show that students can have extreme difficulty with this area—for example, with transferring subject-related theoretical/methodological principles from the discipline courses to the project work. On the other hand, students indicate that teachers have difficulty in delegating responsibility (for the outcomes) to the students and that this makes it difficult for students to exercise their independence when formulating learning goals [23].

When planning themes for PBL and the project proposals, the formation of objectives can occur on various levels. The facilitator can train the students in induction and deduction by helping them to relate their project objectives to the overall objectives. Furthermore, in the evaluation, the focus should not only be on testing the students' depth and breadth of learning, but also on their ability to 'fill in the subject area gaps'.

In the planning, implementation and evaluation phases, it is useful to consider objectives at three levels:

- the overall subject framework;
- themes and types of problems; and
- proposals for the PBL work.

The objectives should preferably be formulated in such a way that they are flexible and allow room

for the formulation of themes, choice of problem types, and formulation of the PBL proposals. Thus, the first step in the deduction and induction process involves getting these three levels to match up with one another. It may be easiest to begin with the specific proposal, but it is also important to ensure that the overriding objectives which these PBL proposals must fulfil are formulated. When something 'misfires' in the course of the actual project, both the student and the teacher must reconsider the project in relation to the general objectives and assessment criteria.

While it is important to consider the objectives when planning the teaching, it is equally important in the implementation of the project and, last but by no means least, in the evaluation. The objectives are also important in the daily supervision of the project, both in the preparation of the student–facilitator meetings and as a component of the shared summarising of the facilitation of these meetings. The objectives are the frame of reference for questions such as: Where will the project lead? Which dominant goals does it fulfil? Which does it not fulfil? Is it necessary to make any modifications? In addition, it is an extremely good exercise for the students to relate their specific project to more general objectives: What are they learning? What is the project an example of? Could they have learned this in another way? This is a way to practise the inductive and deductive thought processes, or to provide a link between the specific experience and the more general level.

DISCUSSION

In comparing the McMaster–Maastricht PBL model to the Aalborg model of project work, both similarities and differences can be found. In particular, characteristics such as the pedagogical idea of problem analysis serving as the basis for the learning process, interdisciplinary features, participation direction and group work are shared. However, there are differences with regard to assignments, assessment and group work. Each of these aspects represent very critical elements in the process, both in terms of the formal and informal learning processes, so there are important differences at the educational model level. However, the two educational models share the same basic learning principles.

PBL education builds on the students' background, expectations, and interests. It is common for students to be motivated to work much harder with the PBL model than with traditional teaching methods. In general, students spend more time on their studies when working with a PBL model than with traditional models. Student participation is much less in conventional courses, where the students have no say in the problem formulation.

There is a connection between the teaching method and the depth and complexity of the learning, as the student may be expected to reach an analytically complex level of comprehension through the project work, which would not be possible in conventional classes. However, while students are reaching this deeper level of learning, they may miss part of the broader perspective or breadth of knowledge. It is therefore an important part of PBL pedagogy to ensure that the student is in a position to fill in any potential 'subject area gaps', if or when at a later point the need arises. This is a necessary skill for all students, especially as an overstuffed curriculum has long dominated engineering education.

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