Understanding how students learn in project-based courses: A review of literature

Larsen, Samuel Brüning; Kjærgaard, Niels Christian; Bigum, Per Valentin; Jacobsen, P.

Published in:
Proceedings of the SEFI 47th Annual Conference

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Understanding how students learn in project-based courses
A review of literature

S. B. Larsen
Center for Bachelor of Engineering Studies
Technical University of Denmark
Ballerup, Denmark

N. C. Kjærgaard
Center for Bachelor of Engineering Studies
Technical University of Denmark
Ballerup, Denmark

P. V. Bigum
Center for Bachelor of Engineering Studies
Technical University of Denmark
Ballerup, Denmark

P. Jacobsen
Department of Management Engineering
Technical University of Denmark
Lyngby, Denmark

Conference Key Areas: New notions of interdisciplinarity in engineering education, New Complexity quest in engineering sciences (these are the best fit from the list)

Keywords: Project-based learning, Problem-based learning, Learning facilitation, Literature review

ABSTRACT
Project-based learning is a key ingredient in most engineering education programs. Trained instructors that use traditional classroom teaching methods can often easily spot when students grasp key learning outcomes simply by observing students’ face and body language. However, in project-based courses instructors only interact occasionally with students (e.g. in supervision meetings, milestone meetings, and lab exercises). At exams, students demonstrate that they have indeed grasped the course’s key learning outcomes. But how? And why? That project-based courses

1 Corresponding Author
S. B. Larsen
sbla@dtu.dk
result in deep learning with long retention is well documented in literature. However, under-researched is the question of which particular circumstances induce or facilitate the learning. The purpose of this study is to gain a better understanding of the causes for learning in project-based courses. To identify the learning-inducing causes in project-based courses, this study reviews extant literature. Three distinct categories of learning-inducing causes appear in the literature: instructor-directed learning, team-directed learning, and individual self-directed learning. The study presents results within each category. One distinct finding is how the team’s application of the project methodology facilitates several important means for learning. Examples are (a) breaking down a project into its components parts and (b) summarizing and presenting progress in status reports and pitches. Literature focuses (perhaps not surprisingly) on how instructors can facilitate learning. Missing in literature are learning-inducing causes related to the individual student and, in particular, the students relations to outsiders on and off campus.

1 INTRODUCTION

Project-based learning is a key ingredient in most engineering education programs. Often, engineering education programs begin with math and natural science disciplines; continue with disciplines about methods, tools, and techniques; and end with courses concerned with the application of these methods, tools, and techniques. These latter course type often take the shape of a project-based course, where students work in teams to develop a solution using the discipline’s tool box [8]. Depending on the engineering discipline, a solution could be an engine, a building, a production system, or a chemical process.

For second or third semester projects, student teams might receive project descriptions that include a detailed set of project requirements. Later in the education, student teams often cooperate with an external partner, who supplies the problem to be solved [2]. Such a problem usually takes the shape of either a defined solution need or that something existing is unsatisfactory or simply has an improvement potential. Examples of solution needs are a need for new building with sixty stories or an app with a fast launch speed. Examples of something existing that needs improvement could be a production system’s high scrap rate or a machine’s short longevity [9].

While the end result of a project differs widely, students must often learn certain, pre-specified learning outcomes these project-based courses. Examples of learning outcomes are (1) how to apply a technique introduced in an earlier course or (2) how two element from two separate prior courses relate to one-another, and (3) how to sequence the activities in a project that designs a solution to a problem, (4) how one element fits into a greater structure. Students often conduct their work in project-based courses using methods, tools, and techniques learned in earlier courses [7].
These earlier courses are often taught through traditional classroom teaching methods. In these courses, trained instructors can often easily spot when students grasp key learning outcomes because instructors have continuous interactions with the students. Instructors can measure learning simply by observing their students’ face and body language or through classroom assessment techniques. In project-based courses, instructors and supervisors only have occasional interactions with students (e.g. in supervision meetings, milestone meetings, and lab exercises). At the exam of the project-based course, students demonstrate that they have indeed grasped the course’s key learning outcomes. One could ask “how?” or “why?” And so does this study.

That students learn well and with long retention through project-based learning is well documented in educational literature (e.g. [1] and [11]). However, under-researched are the questions of when during a course the learning occurs, how the learning occurs, and (perhaps most important) which particular circumstances induce the learning. The purpose of this study is to gain a better understanding of the latter question. The study seeks to contribute to a better understanding of the causes for learning in project-based courses.

That students grasp key learning outcomes when their supervisor explains issues is well-known. However, other causes that induce learning are only vaguely known or assumed. Do students learn by discussing subjects with one-another, do they learn when explaining subjects to friends and family, when biking to school, when conducting individual project tasks, or perhaps in the shower? This study will reveal what extant literature holds of answers and suggest avenues for future research into unknown territory.

2 METHODOLOGY

To identify the learning-inducing causes in project-based courses, the study applies the literature review methodology that is adapted from the tradition in the medical sciences (see [10] for an example). The study will apply the research protocol illustrated in Figure 1. First, the study locates papers; second, the study screens papers for relevance; third, data is extracted and, fourth, the study conducts a descriptive analysis of the selected papers and provides a thematic analysis following the particular purpose of the study, which is to identify and categorize the causes for learning in project-based engineering education courses.

<table>
<thead>
<tr>
<th>Location of papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screening papers for relevance</td>
</tr>
<tr>
<td>Data extraction</td>
</tr>
<tr>
<td>Descriptive and thematic analysis</td>
</tr>
</tbody>
</table>

Fig. 1. Research protocol
To locate the right set of papers, the study applies the search engine from the Technical University of Denmark, called *DTU FindIt*. This search engine provides results from most major scientific databases, including Web of Science and SCOPUS. The authors of the study are all instructors within industrial and manufacturing engineering, so to ensure a thorough understanding of the selected papers, the study limits the search results to papers about engineering education within these subjects. The study applies the following search string:

"engineering education" AND project AND learning AND ("industrial engineering" OR "manufacturing engineering" OR "production engineering")

The search engine provides the option of selecting journal articles only, and this selection results in 410 hits. These 410 hits were screened for relevance by reading title, abstract and keywords. The screening resulted in 73 hits. The screening criteria was whether the paper contains descriptions of the learning-inducing causes in project-based courses. Included were also papers where the abstract leads to believe than the paper itself will provide relevant content. These 73 papers serve as the data for the study and the study will therefore extract descriptions of learning-inducing causes from the dataset. Some causes will be well-described in a paper, while others may just be mentioned and some even just assumed.

As mentioned, the study will conduct both a descriptive analysis of the selected papers and a thematic analysis that will categorize the learning causes. The descriptive analysis will analyze the dataset by examining publication years and journal outlets. The thematic analysis will inductively develop a set of categories of learning-inducing causes and within these categories provide cause-descriptions.

3 RESULTS

This section presents the results of the study findings. First, section presents the descriptive analyses and, second, the thematic analysis.

3.1 Descriptive analysis

Table 1 shows how the selected set of paper are distributed over time ranging from 1999 to the present, and across journals.

The table shows an increasing trend in researching learning through project-based courses. The most prevalent journal in the study is the *International Journal of Engineering Education*, while the *ASEE conference* is the largest outlet on the conference scene. Other than these two outlets, the topic appears to be relevant
across a large range of journals. 28 of the 73 papers are published as the only publication on the subject within the outlet. Perhaps a bit surprising is the difference between the *International Journal of Engineering Education* (17 publications in the study) and the *Journal of Engineering Education* (two publications in the study).

**Table 1. Descriptive analysis**

<table>
<thead>
<tr>
<th>Distribution across time and journals</th>
<th>Number of papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
</tr>
<tr>
<td>Before 2001</td>
<td>7</td>
</tr>
<tr>
<td>2001-2005</td>
<td>2</td>
</tr>
<tr>
<td>2006-2010</td>
<td>13</td>
</tr>
<tr>
<td>2011-2015</td>
<td>25</td>
</tr>
<tr>
<td>After 2015</td>
<td>25</td>
</tr>
<tr>
<td>Journal</td>
<td></td>
</tr>
<tr>
<td>International Journal of Engineering Education</td>
<td>17</td>
</tr>
<tr>
<td>ASEE Annual Conference and Exposition Proceedings</td>
<td>10</td>
</tr>
<tr>
<td>Proceedings - Frontiers in Education Conference</td>
<td>4</td>
</tr>
<tr>
<td>Advances in Engineering Education</td>
<td>3</td>
</tr>
<tr>
<td>AIEDAM</td>
<td>3</td>
</tr>
<tr>
<td>European Journal of Engineering Education</td>
<td>2</td>
</tr>
<tr>
<td>Journal of Cleaner Production</td>
<td>2</td>
</tr>
<tr>
<td>Journal of Engineering Education</td>
<td>2</td>
</tr>
<tr>
<td>Producao</td>
<td>2</td>
</tr>
<tr>
<td>Other journals with one selected paper</td>
<td>28</td>
</tr>
</tbody>
</table>

3.2 Thematic analysis

In this analysis, the study will seek the answers contained in literature about what induces learning in project-based courses, in which instructors have only occasional student interactions. This section will examine the factors that make students acquire knowledge. To exemplify, one of the basic processes of acquiring knowledge is deduction. A student deduces a logical connection, e.g. between two variables or how a theory or method is properly applied. The study will seek what induces deduction.

Some of the selected papers apply the term instructor-directed learning, which in project-based courses refers to elements of the course that are pre-determined by the instructors (e.g. [1]). Examples are (a) project scoping, (b) description of particular project tasks, (c) mandatory methods or frameworks, (d) a particular sequence of project activities, or weekly assignments [11]. The opposite of instructor-directed learning is student-directed learning. This concept can be divided into learning directed by the *student team* as the actor and self-learning where the individual student is the actor. The following three sections divide the study’s results into the three categories of (1) instructor-directed learning, (2) team-directed learning, and (3) self-directed learning. Each of these category-sections will examine how direction from the instructor, the student team and the individual student, respectively, induce learning.
Instructor-directed learning
Instructors can take several different roles in a project-based course based among others on the degrees of freedom for the student teams. An instructor can take the role as a mentor rather than an instructor or as facilitators or guides [2].

Instructors have a pivotal role in the beginning. One particular task is formulating the project descriptions, which may include a set of specific tasks to be solved. The description will motivate students to seek information (papers, construction codes, industrial practice instructions, textbooks, etc). The task of evaluating theory, methods, models, tool an techniques induces students to think critically and learn about applicability and the context of their application. In addition, instructors often introduce the basic concepts of project planning, team dynamics, reporting, etc. [13]. Applying these concepts induce learning through learning by doing.

Later in the project, instructor-conversations induce learning. Examples of instructor-team interactions are laboratory solution tests and design reviews [15]. These conversations around tests and reviews induce learning about what works and what does not.

Team-directed learning
Team directed learning is the most described means of learning in project-based courses. The following section will go through a number of themes contained in the selected papers.

Problems are often the initial stimulus for learning in project-based courses. Based on the problem, the team develops a structural knowledge frame in which specialist knowledge is embedded [5]. The project plan itself functions as a structural and methodological frame (see a later section).

Brainstorms for solutions are as an explicit stimulus for surfacing potentially useful ideas and concepts [13], and the process of qualifying ideas enables a deductive thought process of “If the objective is X, then criteria for selection is X1 and X2. The current idea works because X1 and X2 critiera are met”. This thought process is often implicit and vague.

Targeted input from non-engineering disciplines “enable new and varied perspectives on a problem” and integrating multiple disciplines help students “weave a tapestry” from seemingly unrelated facts [14].

When visiting the external partner, who provides the problem, and discuss issues with external partner contacts, the team is prompted to think about how potential solutions can fit into the context of the external partner. For example, a student team identifies a feasibility criterion for a solution [4] and needs to satisfy the criterion in the solution design.
Several papers apply writing task as part of their project requirements. When writing solution documentation [11], student teams must formulate their knowledge in writing, which forces students to embed their learning in the logic that is the structure of the documentation. Communicating progress is a learning inducing cause. The team must summarize their work in writing. This could be on a written “one-pager”, as notes for a five-minute pitch or graphically in three PowerPoint slides.

Decision-making activities are key to learning. [3] describe knowledge acquisition in engineering design as being “strictly linked with the progression from the initial need (the design problem) to the final product that is made in increments punctuated by design decisions”. Decisions of potential solutions facilitate discussions of not only pro’s and con’s of one or more alternatives, but also which set of factors to include in a decision [5]. Even simple decisions about how to stack a deck of cards foster discussion [12]. Such a task is relevant in e.g. construction engineering. Other examples are when prioritizing among analytical routes to examine further og among possible elements of a solution to a problem.

Project planning functions as a learning-inducing cause. The team must disaggregate the project’s overall complex task into a set of simpler tasks. When conducting and discussing the disaggregation, the team will learn the logical build-up of the project including the problem and later the solution. A work breakdown structure [2] is often one of the explicit activities in a project-based course that helps with disaggregating a project into a set of logical and solvable component parts.

Self-directed learning by the individual
When conducting individual tasks, each student learns. When applying tools and hands-on experience or when combining methods learned in earlier semesters with the particular problem to be solved in the project ([5] and [6]). An example could be formulating an algorithm using a textbook filled with potential functions.

4 DISCUSSION AND SUGGESTIONS FOR FUTURE RESEARCH
Project-based learning is distinct in the way that it is organized as a sequence of activities. The project’s technical content is embedded in these activities, but the project also includes activities that stem from the project methodology itself. Some of these activities induce learning. The team naturally needs to break down the project into specific activities that can be part of the project plan. In problem-based learning (PBL) breaking down the project enables learning of (a) the natural or logical make-up of the problem to be solved, (b) the activities in a causal analysis of the problem, and (c) the activities in the identification of design requirements for the solution. In addition, the team must often report progress. Developing the message in an often predefined format enables learning by having to formulate messages, hone their argumentation skills, and develop graphical displays.
The study reveals that team-related themes are much more researched than issues related to the individual students or the individual student’s larger context. Future studies could focus on learning through students’ individual tasks, and how ideas often appear to the student seemingly like a bolt from the blue. In addition, how much learning happens when students discuss their work with outsiders (friends or family)? This has yet to be examined.

Team processes can be frustrating. Students learn from their own emotional reactions to situations and also from the reactions from other team members. They learn what makes themselves and their team perform well and which pitfalls to avoid. Future studies could examine how students learn from being present, having emotions, and react to project situations.

Several papers discuss design processes and the concept of problem-based learning (PBL). A project-based course is an effective method for facilitating PBL and learning design thinking and design processes.

Results show a number of papers discussing the motivation for running project-based courses. Teamwork, communication, critical thinking and other professional skills are key to early career success. Project-based courses are pivotal for developing these “soft skills”.

Many of the selected papers evaluate how a particular approach to project-based learning impacts learning (often measured in GPA-increases). Perhaps the prevalence on these studies is explained by the popularity of the Scholarship of Teaching and Learning concept where practitioners are encouraged, measured, and often promoted based on their ability to reflect and research the effectiveness of their own teaching methods.

Finally, the study did not find much information about the relationship between the project-based course and the earlier courses that form the theoretical foundation for the project-based course. Perhaps future research could examine this relationship as it related to the team’s and individual’s learning.

5 CONCLUSIONS

The study has found three distinct categories of learning-inducing causes: (a) instructor-directed learning, (b) team-directed learning, and (c) individual self-directed learning. The paper presents sets of learning inducing causes in each of these categories.

One distinct finding is how the team’s application of the project methodology facilitates several important means for learning. Examples are (a) breaking down a project into its components parts for the purpose of planning the project, (b)
summarizing and presenting progress and key facts in status reports and pitches, and (c) discussing designs and ideas with faculty during milestone meetings.

Literature focuses, perhaps not surprisingly, on how instructors can facilitate learning and on the learning processes of the student team. Missing in literature are learning-inducing causes related to the individual student and, in particular, the student’s educational context (e.g. relations to others on and off campus).

REFERENCES


