Engaging Students in Secondary Science Learning through the Scientific and Engineering Practices and Use of Digital Tools

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Abstract

Policy documents have suggested that school science should represent real scientific and engineering practices and use of digital tools, in order to raise students' low levels of interest and engagement in science learning. In this study, a quasi-experimental design was used to test the effect of Project-Based Learning (PBL) and use of digital tools on the engagement and learning of upper secondary students. The experimental group (n = 29) was taught using a PBL Newtonian mechanics teaching module, and the control group (n = 25) was taught using traditional teacher-delivered lessons and practical work. Students' engagement was measured using an experience sample (ESM) instrument, and their achievement of learning outcomes was measured using a cognitive test. We found that the PBL teaching module, which emphasized collaboration, the use of scientific and engineering practices and use of digital tools, engaged students in learning and supported them in achieving learning outcomes better than traditional teaching.

Keywords

Project based learning, Scientific and engineering practices, digital tools, engagement.

1. Introduction

The Organization for Economic Co-operation and Development [10] designate that science is not just test tubes and the periodic table. Science is the basis of nearly every tool we use every day, like a simple can opener to the space explorer or the latest medical advances. Nor is science the domain of scientists only. Everyone now needs to be able to "think like a scientist": to be able to weigh evidence and come to a conclusion; to understand that scientific "truth" may change over time, as new discoveries are made, and as humans develop a greater understanding of natural forces and of technology's capacities and limitations.

Students' low interest and engagement in science learning has been recognised worldwide [11] [16]. The percentage of students in Finland who agreed or strongly agreed with the statement, "I enjoy acquiring new knowledge in science" has decreased from 64% in 2006 to 56% in 2016. In 2016, the percentage of Finnish students who expected to be working in a science-related occupation at age 30 was the lowest among OECD countries [12]. Therefore, in Finland, there is a need to develop more engaging science teaching.

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Due to this, the new Finnish curriculum framework has emphasised the importance of student engagement in science learning [4]. The curriculum has suggested that students' engagement could be supported through contextualising learning and focusing on core scientific knowledge and practices, including practices with digital tools to expand their knowledge acquisition. Scientific practices involve students in asking questions and defining problems, planning and carrying out investigations[21], analysing and interpreting data, and developing explanations and designing solutions. The curriculum is in line with the European Commission's Horizon 2020 Work Programme [3], which suggested that school science should represent real scientific practices and cater effectively to the needs and interests of young people.

Another issue, the various countries and organisations, like OECD and European Union emphasizes is the use of digital tools in teaching and learning. According to the description in the Finnish curriculum of what is involved in learning digital competences, students should first be able to do the following:

- learn to use digital tools in diverse and creative ways
- collaborate and network with digital tools; and
- work with data, information, and
  knowledge. Second, the student should be
  guided in the following:
- critical and creative knowledge practices, such as searching information and generating ideas;
- collaborative knowledge-building and the use of knowledge in different situations; and
- constructing and working with abstract artefacts, such as texts and concept maps, and concrete artefacts, such as scientific models and modelling, with digital tools in different in- and out-of-schoolearning environments.

2. Project-Based Learning

Project-Based Learning (PBL) is an approach that lets use multitude of strategies to learning. The students drive their own learning through inquiry, as well as work collaboratively to research and create projects that reflect their knowledge. The students learn technology and communication skills, and advanced problem solvers.

- Krajcik and Shin [7] emphasised the following characteristics of PBL:
- PBL starts with a driving question, that is, a problem to be solved and focuses on the learning goals of the curriculum that students are required to master
- Students are active in learning and explore the driving question by participating collaboratively in scientific and engineering practices, including practices with digital tools, that are central to expert performance in the discipline. They, for example, investigate questions, propose explanations, and argue for their ideas.
- Students create a set of tangible products, like graphs and tables with digital tools that address the driving question. These are shared artefacts, that is, publicly accessible external representations.

The definition of PBL fit well with the description of aims of science education and role of digital tools in education in Finnish curriculum. The science curriculum emphasises: learning of disciplinary core ideas, which are important (across science and engineering domains); explanatory (used for explaining phenomena); generative (used for investigating and solving problems); relevant (personal, local, global contexts). The curriculum emphasizes also the use and learning of scientific practices or the ways scientists and engineers study and design environment:

- asking questions, defining problems;
- planning and carrying out investigations;
- analyzing and interpreting data;
- developing and using models;
- using mathematics and computational thinking;
- developing explanations and designing solutions;
- engaging in argument from evidence; and
- obtaining, evaluating, and communicating information

Moreover, the curriculum emphasizes that students have an active role in knowledge building and collaboration. The aims in the science curriculum are in line with what is described as important related tpo the use of digital tools in learning as described above. Consequently, the curriculum is in line with and could be implemented in classrooms through PBL, which is a pedagogical approach designed according to learning science research outcomes.

Multiple educational projects have been developed by implementing PBL in science education. [5], examined the effectiveness of Science, Technology, Engineering, and Mathematics project-based learning lessons on students' achievement in algebra, geometry, probability and problem solving. Their study shows higher scores in geometry, probability, and problem solving than those in non-Science, Technology, Engineering, and Mathematics project-based learning schools.

Also, Han et al. [5] [17] proposed a quasi-experimental design where quantitative data from three focus groups were collected to assess student engagement within a STEM PBL classroom compared to a non-STEM PBL classroom. They performed the exploratory factor analysis to more closely examine the 8 engagement structures and resulted in the creation of two higher order factors,

(1) academic engagement (AE) and (2) behavioral engagement (BE). These results were used to verify that there exists an improvement in student academic engagement between the intervention groups, comparing traditional mathematics lessons verses STEM PBL lessons. The results showed that the academic rigor and relevance provided through STEM PBL lessons increase students' academic engagement.

On the other hand, Graig et al. [1] found that students taught through PBL, as a group, matched performance of conventionally taught students on all science 11th grade and mathematics 9th, 10th, and 11th grade TAKS achievement measures and exceeded performance by a scale score increase of 133 for the 10th grade science TAKS measure by ($B = 133.082$, $t = 3.102$, $p < .05$).

Also, a recently research by Putri al. [13] present study is to examine the improvement of creative thinking skill of primary school students in science through project based learning (PBL). Their research used quasi experiment with non-equivalent control group design. The study involved 45 fifth grade students at a public primary school in Karawang, West Java. The students were divided into two groups i.e. experimental group (n=24) and control group (n=21). The students in experimental group were given instruction through PBL; meanwhile, the control group was involved in traditional instruction. Creative thinking test was used as pre- test and post-test to both groups. The data were analyzed by using independent sample t-test to compare the creative thinking score between the experiment and the control group. The result showed that the students in experimental group had better creative thinking skill rather than the students in the control group. It can be concluded that project based learning can effectively improve creative thinking skill of primary school students in science class.

We approached situational engagement in the context of flow theory [2][14]. To be engaged, a student should experience content- and context-specific situational interest in the task, which depends on knowledge, values, and feelings. Second, students' skills and mastery of a set of specific tasks should be related to the activity, and the task should be at an appropriate level (situational resources). Third, students should experience elevated levels of challenge and a desire to persist in a science learning situation (situational task demands).

However, little is known about students' engagement in scientific and engineering practices and how teachers can employ these practices in their classrooms [9][15]. Therefore, a six-lesson (75 min) PBL- module of basic Newtonian mechanics was designed in partnership with teachers and researchers and implemented in a class (n = 29) as part of their first comprehensive physics course in upper secondary school. Moreover, there was a control group of equal size.

The research question of the study was, "How did PBL teaching modules support students' engagement in science learning and their achievement of expected learning outcomes?"

3. Method

3.1. Design of a PBL teaching module

Nonaka et al. argue that changes in professionals' [10] [19] practices build on professional learning or knowledge creation processes that span individual, and group levels where interacting with peers and seeking help from more expert professionals are important. Therefore, for teacher networks and partnerships with researchers could support the design and adoption of new pedagogy related to engaging science teaching, reflection, and sharing and generating new ideas or pedagogy. This type of research–practice partnership (RPP) has been suggested for bridging the gap between educational research and practice and consequently, supporting teachers' professional learning [6] [21].

We engaged in an RRP with 20 secondary science teachers for co-designing, implementing, and reflecting on teaching units, emphasizing science and engineering practices, student collaboration, and construction of artifacts to enhance student engagement. This teacher–researcher partnership is expected to support teachers' professional learning on pedagogy related to engaging science teaching.

The designed six hour teaching module focused to Newtonian mechanics and the driving question was decided as: "Why do some objects take different amounts of time to fall from the same height?" According to the learning outcomes of the module, students who demonstrate an understanding of basic Newtonian mechanics can do the following:

- analyse data on motion, recognise when objects move with constant or changing velocity, and use the basic models for motion with constant velocity and constant acceleration in problem solving;
- analyse relationships among the net force on a macroscopic object, its mass, and its acceleration and use Newton's second and third laws in problem-solving;
- apply scientific and engineering practices to design, evaluate, and refine an experimental design that could be used for modelling previous topics.

Following description of one lesson is made based on the video captured during the lesson. The teacher starts his lesson through introducing the topic: "This week we will investigate to different kinds of movements and reasons behind the movements. We will experiment and discuss. And you should make a report based on your project [Project Based Learning activity]". The driving question is "why objects fall to the ground – sometimes at the same time and sometimes not at the same time".

"In order to understand the driving question and pose relevant research questions we will start with a demonstration. We will discuss on your observations and your conclusions and the evidence you use". In the demonstration same shape but different mass objects were given to fall and it was happening what was not according to expectations. During the demonstration the teacher push his students to wonder and come curious and the driving question comes understandable and it was supportive for students' thinking and posing relevant research questions for the next phase.

The students were asked write down questions related to the movement of a falling body and questions related to reasons of the nature of movement. Students start working with the questions. Later the questions were analyzed and discussed together.

The teacher summarizes the experiences: "This was the orientation to this week. We will explain later what we observe. You might be wondering now. Let's start studying the phenomena. However, we have to split it down and study it part by part according to your questions. This is not a simple phenomenon. There are many issues. You should have this phenomenon in your mind while we are answering the guiding question."

Next, the teacher shows a video clip considering the racket leaving Earth. The teacher explains that this phenomenon actually belongs also to the topic they will analyze. The teacher asks students to compare the phenomenon to a ball, which is thrown towards the sky. Similarities and differences were discussed. The questions, students posed after the demonstration were analyzed and slightly modified. The teacher told that they will start with the questions related to movement. Among the questions there were questions, like "is the velocity constant?"; "How the movement change or is not changing?"; How the velocity change, if it change?".

Teacher: "Now we will engage in making experiments according to your questions. Here we have equipment. You are free to use Microcomputer Based Laboratory (MBL) tools. For example ultrasonic sensor could be useful." After the introduction, the students start investigating according to their research questions or engage in collaborative knowledge construction through employing scientific knowledge practices. The students start planning their investigation according to their questions. The investigations are focusing to modeling of movement of different falling objects. Student are systematic in their activities according to the. While students are planning and working the teacher walk around the classroom. He is asking questions and helping students to focus to the topic. The teacher asks students, for example, “How do you feel when the lift goes up. Or actually start to go up. How do you feel when the lift starts to go down? Please, think about what you feel in your body”. This type of guiding helps students to orient to recognize the link between the net force and change in movement. After the measurements, the students use long time in negotiating, modeling and communicating. The models they created were models (artifacts) for two different type of movement (movement with constant velocity and movement with constant acceleration and the preliminary reasons for the change in velocity.

The driving question, “Why objects fall to the ground – sometimes at the same time and sometimes not at the same time?” was partly solved. The students recognized that heavy objects accelerate the whole falling and light object only a short distance. However, the reason for the change in movement did not become fully clear.

3.2. Design of the study and data collection

A quasi-experimental design was used. The experimental group (n = 29) was taught using the designed PBL module. The control group (n = 25) was taught using traditional teacher- delivered lessons and practical work. The same teacher taught both groups.

The experience sample method (ESM) was used to evaluate how well students in the experimental and control groups engaged in science learning through a specific smartphone application [14] [8]. In the ESM questionnaire, 4-point Likert scale items were used to measure students’ situational interest, skills, and challenges. We operationalized engagement as a state of involvement in a learning task identified by higher- than-average individual states of interest, skill, and challenge. Moreover, students were asked to select the type of science practice undertaken and whether they collaborated with other students when signaled.

We used the taxonomy of Bloom, as a starting point for the design of test items to measure the learning outcomes of the designed module. The dimension of cognitive processes was reduced to three levels: remember, understand, and apply and create. Second, we took into account the national curriculum framework aims and scientific (knowledge) practices emphasized in the PBL model. [18] The scientific practices involved students in asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, developing explanations, engaging in arguments from evidence, and communicating information. The curriculum has emphasized the use of conceptual and procedural scientific knowledge in three situations: explaining phenomena scientifically, designing and evaluating scientific inquiry, and interpreting data and evidence scientifically. The same computer-based test, with 13 items, was used as a pre- and post-test for both groups. Figure 1 shows two test items.

012. A relevant research question	**04. Forces acting on a ball**
1 Take a look at this video related to a moving sledge. http://youtube.com/watch?v=3pk8gOFgmnw 2 Pose two questions on the basis of which it is possible to examine the links/correlation betweenvariables relating to the phenomena in the video.	1 Watch a slow-motion video of someone kicking a football. Http://youtube.com/watch?v=v0zowDrCbE s 2 Take a screenshot from the video and paste it to a drawing program of your choice. Draw all forces acting on the ball in the picture. Name the forces.

Figure 1: Two examples of test items.

4. Results

Table 1 shows the engagement of students from each group in scientific practices and working in a group. Altogether, during the six 75 min lessons, there were 465 randomly-selected engagement measurements in the experimental group and 445 measurements in the control group. Students in the experimental group reported participating in more scientific practices.

than those in the experimental group, except for the practice of "using models". Moreover, students in the experimental group found most scientific practices and working in a group more engaging than control group students. However, the differences between the groups were statistically significant only for the practices of "developing models" and "making arguments".

Table. 1a.
Scientific practices and percentage of engaging situations in the experimental (n = 29) and control (n = 25) groups.

	Experimental group		Control group	
Scientific Practices (SP)	Number of SP	Percentage ofengaging SP	Number of SP	Percentage ofengaging SP
Asking questions	14	6%	13	4%
Developing models	79	38%	62	18%
Using models	19	15%	36	15%
Planning investigations	37	17%	22	7%
Conducting investigations	102	17%	80	18%
Analyzing data	98	30%	80	21%
Solving problems	23	9%	22	12%
Constructing explanations	84	26%	67	19%
Making arguments	19	23%	13	4%
Evaluating information	116	32%	111	23%
Other	74	6%	147	25%
Total without other	591	26%	506	18%

Table. 1b.
Group work, and percentage of engaging situations in the experimental (n = 29) and control (n =25) groups.

	Experimental group		Control group	
Scientific Practices (SP)	Number of SP	Percentage ofengaging SP	Number of SP	Percentage ofengaging SP
Working in a group	93	13%	10	10%

There was no statistically significant difference between experimental and control group performance in the cognitive pre-test. However, the experiment group performed better in the post-test. The difference in performance was statistically significant (Table 2).

Table. 2.

Experimental and control group students’ performance in pre- and post-tests.

	Experimental group		Control group		*F*
	Mean	S.D.	Mean	S.D.	
Pre-test	10.7	3.6	10.2	4.0	0.27^{ns}
Post-test	15.3	2.7	12.0	3.9	13.1***

5. Discussion

We inferred that the implementation of the designed PBL made the difference. [9] argued that few research papers have addressed students’ engagement in scientific practices and how teachers can be guided to organize engaging science education. According to our pilot quasi-experiment, we inferred that a designed upper secondary PBL Newtonian mechanics teaching module was better at engaging students in learning and supporting students to achieve expected learning outcomes than traditional, teacher-delivered lessons and practical work. The percentage of scientific practices in which students were engaged was about 10% higher than in our previous measurements in traditional Finnish and US science classes or in our control group class [14].

We interpret our results so that the BPL approach helps a teacher to integrate the curriculum aims for science learning and aims related to the use of digital tools in learning. Moreover, the PBL approach is supportive for learning and engagement. We summarize the characteristics of PBL in line with Krajcik and Shin [7]:

- PBL starts with a contextualizing driving question, that emphasize the learning of disciplinary core ideas through the use of scientific and engineering practices.
- Students are active in learning and explore the driving question by participating collaboratively in scientific and engineering practices, including practices with digital tools, that are central to expert performance in the discipline. They investigate questions, work with data, information and knowledge propose explanations, and argue for their ideas.
- Students create a set of tangible products, like graphs tables with digital tools that address the driving question. These are shared artefacts, that is, publicly accessible external representations. These external representation are used for collaborative development of models which are describing the phenomena which was inquired.

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