Water and wind turbines optimisation using inquiry-based teaching: a Chain Reaction case study

Veronika Šinigoj & Stanislav Avsec

University of Ljubljana
Ljubljana, Slovenia

ABSTRACT: The purpose of this study was twofold: to investigate the effect of reproductive and productive learning integrated in the context of inquiry-based teaching (IBT), and to find the impact of students' attitude toward technology within technological literacy. Educators are interested in IBT because of its emphasis on active, transferable learning and its potential for motivating students. IBT effectiveness in technology and engineering is not stable yet. For this purpose, a didactical model for a technology-intensive IBT course of water turbine optimisation based on constructivist productive theory was designed, and a wind turbine optimisation grounded on constructivist reproductive open learning. For this purpose, 233 middle school students were recruited in a 2-year pedagogical experiment of the Chain Reaction project, which was conducted in 2014 and 2015 at 10 middle schools. Statistical analyses revealed that IBT productive learning is significantly ($p < 0.05$) more effective at technological literacy gain than the reproductive learning approach with a large effect size (Cohen's d = 0.88). Several suggestions are presented to improve the implementation of IBT.

INTRODUCTION

Inquiry-based teaching (IBT) was born of the longstanding dialogue about the nature of learning and teaching. Most notably involving the constructivist work of Jean Piaget, Lev Vygotsky and David Ausubel [1]. The constructivism approaches include hands-on activities as a way to motivate and engage students; furthermore, constructivist approaches emphasise that knowledge is constructed through active thinking by an individual [1]. IBT reflects Dewey's belief that students need to develop critical thinking rather than memorisation skills. The term IBT refers to instructional practises designed to promote the development of high order intellectual skills. Inquiry as a teaching method seeks to develop inquirers and to use curiosity [2]. IBT was very popular in the 1960s and early 1970s in technology or engineering education [3]. It is a very popular method mainly because of its authentic and real-world problem-solving scenarios and because students have control of their own learning [4]. Several studies have found IBT methods positively affect student performance [5].

Since 2013, the Faculty of Education at the University of Ljubljana has participated in the Chain Reaction project as a core partner. The project is scheduled for three years and makes an effort to promote and to exploit IBT methods in science and technology teaching. In addition to the purpose of the project, it is also to confirm that IBT is an effective method for teaching science and technology. Students develop problem-solving skills, teamwork, organisation, communication and research skills. Students work in groups, research scientific scenarios using critical thinking, reasoning and problem-solving skills. The most successful students show their work and presentations at national events [6].

Research questions are:

- Which teaching approach, productive or reproductive, is more effective for open learning course at the IBT level?
- How do students' motivation and attitudes toward technology contribute to their technological literacy gain?

INQUIRY-BASED TEACHING

Students differ from one another. Some are more passive in class and feel better as receivers of information, but on the other hand, there are active learners. Traditional methods neglected active students. Active learners are frustrated, because it has been proved that they learn better if they can be actively involved in groups, discussions and projects [7]. The IBT method allows students to be active participations and to collaborate with other students, so IBT is a productive approach of teaching. IBT is an inductive learner-centred educational approach in which students follow methods and practices similar to those of professional scientists in order to construct knowledge. It is a process of discovering new causal relations [8]. Learners are active participations who are responsible for discovering knowledge that is new to them [8][9]. Learners are engaged in an authentic scientific discovery process and construct knowledge by doing experiments [8]. IBT involves making observations, posing questions, examining books and other sources of information, planning investigations, analysing and interpreting data, proposing answers, explanations and predictors using critical and logical thinking [9]. Students work in groups, which encourage and develop personal, teamwork, leadership and task completion skills [10]. IBT environments are naturally very open-ended [4]. The classroom is a very important factor to be considered if the intent is active learning. To facilitate students' work, the layout of the classroom has to be changed from the traditional design to a new student-centred design. Because of that, students are encouraged to collaborate and work in groups [9].

Although students are independent, the teacher's role in IBT is very important. He/she serves as facilitator or mentor, offers help to students and gives feedback to students. The teacher supports collaborative and cooperative work. He/she supports students and guides them through discussion. Besides that, the teacher helps students to make connections between their ideas and scientific concepts. Students are not left alone, but are guided by the teacher [3][9].

Creativity and imagination are important characteristics that are expected among new employees in the 21st Century [11]. IBT is a teaching approach that allows learning creativity. Activities in IBT are based on exploration and creativity. Teachers provide experiences that encourage students to use their imagination and to experiment with new ideas and materials, and in that way support creative learning. Teachers should allow students to develop individual skills and self-confidence [12]. Some researchers equate creative thinking with divergent thinking. It can be divided into three areas: fluency, flexibility and originality [11]. Education should inspire, activate and develop creative attitudes [13]. On the one hand, there are productive approaches of teaching; on the other hand, there are reproductive approaches of learning. Reproductive learning approaches mean that students memorise and reproduce information or skills demonstrated by the teacher. There is no creative or critical thinking [14][15].

METHODOLOGY

Course Format

Water turbine optimisation and wind turbine optimisation courses were carried out at 10 Slovenian secondary schools. For each topic, there is an implementation of a 3-day activity course, five periods a day. Activities have been prepared on the basis of inquiry-based learning (IBL), model 5E, which consists of five phases: engagement, exploration, explanation, elaboration and evaluation [16]. There is one difference between the water turbine optimisation course format and the wind turbine optimisation course format. The first course format is a totally productive learning approach, while the other includes characteristics of a reproductive learning approach. Learning processes were based on work in small groups of 3-4 students.

Water Turbine Optimisation

During the three school activity days, students studied in small groups of 3-4 students. Each group investigated existing models and brainstormed ideas to look for parameters to achieve better efficiency for a water turbine. Then, groups designed their own water turbine based on selected criteria. At the end of the course format, students wrote a report of their findings and presented these at a conference. More information about the water turbine course format can be found elsewhere [3][8].

Wind Turbine Optimisation

During school activity days, students learned that wind is a renewable energy source and they measured wind speed with anemometer. They learned that different parameters have an impact on the efficiency of wind turbines. They investigated how the key parameters, e.g. height, number, surface (students changed the blade surface by gluing on sand paper, which had different grainy texture), shape and the blades' inclination angle, impact on wind turbine working and how to achieve better wind turbine efficiency.

On Day 1, students knew basic elements of a wind turbine (blades, rotor, generator, etc) and its operation. They learned about wind speed and power. The teacher showed a simple model of a wind turbine to students. The wind turbine model had a rotor with eight blades, inclined at an angle of 30° and 10 centimetres high. A rotor with blades was elevated 1,500 millimetres. The source of the wind (desk fan) was 40 centimetres away from the rotor, placed so that wind blows directly onto the rotor. Blades were made out of sheet metal and tightened in the wooden rotor by screws. Students' task was to make the same wind turbines as the teacher did (reproduction) in small groups (Figure 1).

Students only made blades and tightened them in the rotor. Teachers had already prepared a stand and rotors. Students made blades from a sheet of metal by cutting them with lever scissors. They drilled a hole for screws and folded the blades. At the end of the first day, they measured the efficiency of their self-created wind turbines. First, they measured the wind speed between the blades. Then, they measured how much time it took to elevate a load for one metre. Students changed loads from 10 to 30 grams and, then, calculated a wind turbine efficiency for each load. On Day 2, students created their own, improved model of wind turbine and measured its efficiency. They compared efficiency of both types of wind turbine and checked if they had achieved the task of constructing a better wind turbine. After that, students wrote reports, made posters or prepared other forms of presentation about their work, findings and measurements at school activity days. These reports were presented on Day 3 to their classmates. Resolving misconceptions and pitfalls followed. IBL was ended with the active reflection.

Figure 1. Students optimise the efficency of a wind turbine.

Sample

The study sample was drawn from secondary school students and comprised 233 eighth- and ninth-grade students aged 14-15. The sex distribution between female and male students was roughly even: 49.79% female students and 50.21% male students. School activity days on turbine optimisation were carried out at ten Slovenian schools, as presented in Table 1.

Table 1. Schools' information and students' distribution.

Middle School	Number
OŠ Bratov Polančičev, Maribor	20
OŠ Koper	22
OŠ Prevalje	26
OŠ Antona Žnidaršiča, Ilirska Bistrica	21
OŠ Draga Kobala, Maribor	34
OŠ Črnuče, Ljubljana	26
OŠ Sežana	26
OŠ Šentjernej	27
OŠ Kranj	18
OŠ Dol pri Ljubljani	14
Total	233

School activity days were held in 2014 and 2015. In 2014, they were attended by 47.64% of students. In 2015, 52.36% of students attended. 60.52% of students attended the water turbine course, while the wind turbine course was attended by 39.48% learners.

Instruments

As a pre- and post-test, the Technological Literacy tests were used. Item distribution was classified into three subscales; namely: a) technological knowledge (TK); b) capacity for problem-solving and research (CA); and c) critical thinking and decision-making ability (CTDM). The water turbine optimisation course in 2014 and 2015 was tested with 15-item test, five items in each subscale. The correct (best) answer (or combination) was scored as 1 point, while distracters were 0 points. A total score on the test was 15. The optimisation of an airborne wind turbine was tested with two versions of the Technological Literacy test, namely, the version of 2014 with 16 items, divided into three subscales non-symmetrically (TK - 9 items, CA - 3 items, CTDM - 4 items). The correct answer was scored as non-symmetrically from 1-3 points. A total score on the test was 27. A test version in 2015 was of symmetrically distribution of items into subscales (6 item in each). The correct (best) answer (or combination) was scored as 1 point, while distracters were 0 points. A total score on the test was 18.

As a measure of course effectiveness, the *average normalised technological literacy gain* (TLG) was calculated. The TLG expressed with *g* in Equation (1), is defined as the average actual gain *G* divided by the maximum possible gain [17],

$$\langle g\rangle = \%\langle G\rangle/\%\langle G\rangle_{max} = (\%\langle post\rangle - \%\langle pre\rangle)/(100 - \%\langle pre\rangle), \quad (1)$$

where *G* is the actual gain and %⟨post⟩ and %⟨pre⟩ are the final (post) and initial (pre) class averages, and the angle brackets ⟨…⟩ indicate an average of the students taking the tests.

For surveying students' attitude toward technology, a reconstructed 25-item test of Pupils' Attitude Toward Technology [18] was used. The survey also included 10 questions on demographics. Demographic questions covered sex, age, family background and home education background. The instrument developed in the Slovene version involved six constructs: 1) technological career aspirations (TCA) - 4 items; 2) interest in technology (IT) - 6 items; 3) tediousness towards technology (TTT) - 4 items; 4) technology across the sex (TS) - 3 items; 5) consequences of technology (CT) - 4 items; and 6) technology difficulty (TD) - 4 items.

For the assessment, a 5-point Likert scale was used. This research treated scale questions as being equal-interval, to enable the investigation of the nominal properties (whether the responses are different), the ordinal properties (which response has the greater magnitude) and the interval property (the distance between two responses). The intervals of the scale together form a continuous type, from 1 (*very unlikely*) to 5 (*very likely*). It does not present the mean, but ensures the comparability of continuous responses. The Cronbach's alpha values, calculated based on the samples of this study, indicated the developed instrument is reliable (Table 2), all Cronbach's alpha values are > 0.60.

Table 2: Reliability information expressed with Cronbach' α on TL tests and *Technology and me* survey subscales.

Year	Water turbine optimisation TL test	Airborne turbine optimisation TL test	Technology and me survey					
			TCA	IT	TTT	TS	CT	TD
2014	0.67	0.68	/	/	/	/	/	/
2015	0.65	0.62	0.91	0.77	0.61	0.84	0.90	0.71

Procedure and Data Analysis

Students participated in the study during actual classroom sessions throughout a 3-day open learning turbine optimisation course. With individual or group administration, testing with one version takes 15-20 minutes. A pre-test *Technology and me* survey was applied before the turbine optimisation open learning course on Day 1, while the post-test was used after Day 3, when the optimisation learning course had been completely finished. A high response rate was obtained, because of the direct presence of the teacher, instructor and test administration. A paper and pencil survey was distributed accordingly. The majority (n = 233, 86.3%) of enrolled students completed all four surveys considering the pre- and post-test and one-shot survey *Technology and me* (missing values n_m = 37, 13.7%). Data analysis was conducted using SPSS software (v.22). Descriptive analyses were conducted to present the students' basic information and the mean score of dependent variables. A *t*-test analysis was conducted to find and confirm significant relationships within, and between groups, with an effect size calculated with Cohen's d. Multiple regression analyses were performed to investigate whether predictor variables significantly predict TL gain. Multivariate analysis was conducted to find and confirm significant relationships between groups with an effect size.

RESULTS

The findings are reported as descriptive analyses of survey data, *t*-test analyses and multiple regression analyses. The first objective sought to describe the relationship between two groups of IBL students where different approach of teaching was used (productive versus reproductive). Table 3 depicts the average scores of TL gain and its dimensions as the subscales including M - mean and SD - standard deviation.

Table 3: TL gain and its dimensions. Descriptive statistics across type of group (IBL topic/approach).

TL dimension	IBL topic	M (%)	SD (%)	n
TL gain	Water turbine	14.37	16.82	141
	Airborne wind turbine	0.01	23.98	92
	Total	8.70	21.12	233
TL_{TK} gain	Water turbine	16.89	44.31	141
	Airborne wind turbine	10.40	38.32	92
	Total	14.33	42.08	233
TL_{CA} gain	Water turbine	15.85	29.61	141
	Airborne wind turbine	-13.55	51.15	92
	Total	4.24	41.99	233
TL_{CTDM} gain	Water turbine	3.82	26.32	141
	Airborne wind turbine	-18.80	42.96	92
	Total	-5.11	35.56	233

A *t*-test revealed a significant improvement in TL from pre- to post-test, t (232) = 8.154, $p = 0.00 < 0.05$. The effect size of IBL training is regarded as high, Cohen's d = 1.07. A *t*-test of between subject effects also revealed statistical significance ($p < 0.05$) between the groups in TL gain, TL_{CA} gain, and TL_{CTDM} gain t (148) = 5.11, Cohen's d = 0.88; t (131) = 4.99, Cohen's d = 0.87; t (135) = 4.52, Cohen's d = 0.77, respectively). An effect size of IBL water turbine optimisation course was regarded to be high. A component of TL_{TK} gain, no significant ($p > 0.05$) differences were detected (t (231) = 1.15). All significance tests for the results were two-tailed. The *class average normalised gain* TL was < 30%, which is regarded as a low gain course [17]. Eighty-nine negative gains were noted. Considering only positive gained students, the *average of the single-student normalised gains* was significantly (p < 0.05) higher in the water turbine optimisation course (M = 22.86%) than in the airborne wind turbine optimisation course (M = 18.14%), which still present low gain courses [17]. Between the sexes, female students scored higher (M = 10.67%, SD = 16.56) versus male students (M = 6.43%, SD = 24.23%). No significant ($p > 0.05$) differences were found.

The second objective was to describe students' attitude toward technology, classified into six subscales. Table 4 depicts the average scores on the subscales. The table shows that student perception toward technology seems to be positive. Students seem to be aware of the consequences of technology on society, and have a positive opinion about the importance of technology and engineering lessons in the regular curriculum. Students were still convinced that boys are more capable than girls at technological tasks. Surprisingly, students perceived the difficulty of technology and engineering as appropriate.

Table 4: Average score on each subscale on students' attitude toward technology with a mid-point 3 (n = 122).

Subscale	M (%)	SD (%)
Technological career aspirations	2.31	1.11
Interest in technology	3.23	0.91
Tediousness towards technology	2.02	1.01
Technology and sex	3.07	1.37
Consequences of technology	3.99	0.73
Technology difficulty	2.56	0.83

Multiple regression analysis was performed to see how much the independent variables can predict student TL gain. The result revealed that the combination of the independent variables significantly predicts student TL gain (F (6, 115) = 2.37, p = 0.026 < 0.05). Approximately 23% of the variance in student TL gain was accounted for by the predictor variables. The explained variances were calculated using R^2 from the path model where $R^2 = 0.02$ - a small impact, $R^2 = 0.13$ - a medium effect size, and $R^2 = 0.26$ presents a large effect size [19].

Students' attitudes toward technology contributing to course outcomes (TL gain) were investigated. A multiple regression analysis was carried out with the items of students' expectations as independent variables and TL gain and its dimensions as achievement variables as dependent variables. A linear relation between independent (predictor) and dependent (criterion) variables was assumed, meaning that one would expect that increases in one variable would be related to increases or decreases in another. Only regression coefficients (β - weights) with a significance of $p < 0.05$ were considered. Beta (β) weights describe the relation between a predictor and a criterion variable after the effects of other predictor variables have been removed. They range from -1 to 1 (0 means no relation at all; 1 or -1 mean that variations in one variable can be explained completely by variations in another). When interpreting results, one has to keep in mind that multiple regressions do not explain causes and effects, but instead describe relationships between variables or sets of variables. A summary of multiple regression analyses is shown in Table 5.

Table 5: Summary of multiple regression analysis for TL gain on students' attitudes towards technology (n = 122).

Importance of:	Acquiring of:											
	TL			TL_{TK}			TL_{CA}			TL_{CTDM}		
	B	SE B	β	B	SE B	β	B	SE B	β	B	SE B	β
Technology career aspirations	-4.49	2.58	-0.22	/	/	/	-3.45	3.97	-0.11	-6.42	4.45	-0.18
Consequences of technology	4.74	3.44	0.15	16.19	7.31	0.25	-5.91	5.31	-0.13	16.81	5.95	0.31
Technology difficulty	-2.86	2.67	-0.11	-4.41	5.67	-0.1	-6.92	4.11	-0.17	/	/	/
Technology is for males	/	/	/	3.41	3.37	0.1	/	/	/	/		/
Interest in technology	3.54	3.66	0.15	/	/	/	/	/	/	/	/	/

Students' attitude towards a career in technological and engineering jobs significantly ($p < 0.05$) predicts TL gain and its two dimensions of CA and CTDM. Students who had no interest in future engineering and technological jobs advanced less in TL. Students who highly perceived the importance of technology, advanced more in TL, TL_{TK}, and TL_{CTDM}, while surprisingly, their problem-solving capacity is not developed yet or perceived self-efficacy is overestimated. A perception of difficultness of technology caused problems in acquiring TL when they undertook IBL courses. Surprisingly, students with a positive attitude to male technological jobs advanced more at the technological knowledge dimension. Design and technology subject matter was perceived as important in middle school, but these students markedly improved only in their general TL, while a significant ($p < 0.05$) development in other dimensions was still lacking.

CONCLUSIONS

The purpose of this study was to investigate which constructivist approach: productive or reproductive, is more effective for teaching on the IBT level. It was found out that productive teaching method markedly and positively affects technological literacy, especially, on the capacity of problem-solving and research and critical thinking and decision-making ability. There were statistically significant ($p < 0.05$) differences between productive and reproductive approach of teaching. For the technological knowledge component, there was no statistically significant ($p > 0.05$) difference between the productive- and reproductive teaching. It seems that with the reproductive teaching approach, students do not gain higher order thinking, critical thinking, logical thinking and decision making abilities. No statistically significant difference between male and female students was found, meaning that the designed course format suits both. Another research question was about students' motivation toward technological learning. Students, who have no motivation towards technology, advanced less in technological literacy. Students, who have a positive attitude to the consequences and interest in technology, advanced more. A future research is required to obtain generalisation on a bigger sample size, and it will be very interesting to compare the technology literacy of middle school students and high school engineering students.

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