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The effect of the use of an inquiry-based approach in an open learning middle school hydraulic turbine optimisation course

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ABSTRACT: Inquiry-based learning is an inductive pedagogy, which enables learners to construct knowledge, to develop high level reasoning skills, and to increase interest and learning motivation with the use of the contemporary technology-based learning environments. This article describes the design and experience of the new student-centred learning model in an open learning of technology education course, which enables a high level of active self-directed learning. A quantitative research methodology was used to analyse the data collected. Multifaceted nature of inquiry-based learning and its impacts were successfully measured with a technological literacy test. The findings of this study showed that inquiry-based learning is an effective teaching approach in technology education. Impact was judged to be large and positive in technological knowledge acquisition (η^2 = 0.37), in problem-solving skills development (η^2 = 0.29), and in critical thinking and decision-making abilities development (η^2 = 0.16). The proposed model suits both female and male students equally. Therefore, the possibility of successfully applying the model is supported by evidence.

INTRODUCTION

Over the past several decades, conventional explicit instruction has been increasingly supplanted by approaches more closely aligned with constructivist concepts of exploration, discovery and invention, at least in part because of an appreciation of which learning outcomes are most valuable [1]. Allowing students to interact with materials and models, manipulate variables, explore phenomena and attempt to apply principles affords them with opportunities to notice patterns, discover underlying causalities, and learn in ways that are seemingly more robust [2]. Inquiry-based learning (IBL) in technology/engineering education was very popular in the 1960s and early 1970s, together with hands-on experiences learning they formed a basic instructional model [3]. During recent decades, in regard to several models of IBL, a lack of valid and reliable quantitative measurement of IBL achievements can be detected [2-6]. Teachers stayed without real-basis feedback and, therefore, the instruction approach was moved toward project-based learning as an effective inductive learning strategy in technology education [7].

Recent efforts by many researchers [7-15] indicate that IBL was popular and effective. Even more, IBL has been recommended in sciences as a leading instructional strategy, while in technology education some limitations exist [7][13][16]. Limitations have been focused around instructional material, didactic methods and process planning, assessment, and motivating/learning strategies related to level of guidance during inquiry.

Inquiry-based Learning

Inquiry-based learning is a learner-centred approach that emphasises higher order thinking skills [9][10], and can strengthen the links between teaching and research [4][5]. Critical thinking, problem-solving skills and communication skills are more important than simply knowing the content itself [8][17]. Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse, and interpret data; proposing answers, explanations and predictions; and communicating the results [18]. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations; and scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work [18]. It may take several forms, including analysis, problem solving, discovery and creative activities [19].

Inquiry learning begins when students are presented with questions to be answered, problems to be solved or a set of observations to be explained [7]. It was developed in response to a perceived failure of more traditional forms of instruction, where students were required simply to memorise fact-laden instructional materials [20]. Inquiry learning is a form of an inductive learning, where progress is assessed by how well students develop experimental and analytical skills rather than how much knowledge they possess [3][5]. If the method is implemented effectively, the students should learn to formulate good questions, identify and collect appropriate evidence, present results systematically, analyse and interpret results, formulate conclusions, and evaluate the value and importance of those conclusions [21][22].

Several types of inquiry-based learning are discussed in the literature, and they are primarily based on three important qualifiers about the nature of inquiry: the level of scaffolding (amount of learner self-direction), the emphasis of learning, and its scale (within-class, within-course, whole-course, whole-degree) [5]. All models of IBL emphasise the following levels of inquiry that differ from one another in significant ways [8-11][18][23]:

- confirmation inquiry - students are provided with question and procedure, and results are known in advance;
- structured inquiry - students are given a problem and an outline for how to solve it;
- guided inquiry - students must also figure out the solution method;
- open inquiry - students must formulate the problem for themselves.

Prince and Felder make a similar distinction between *teacher inquiry,* in which the teacher poses questions, and *learner inquiry,* in which questions are posed by the students [7]. In *process-oriented-guided-inquiry-learning*, students work in small groups in a class or laboratory on instructional modules that present them with information or data, followed by leading questions designed to guide them toward formulation of their own conclusions [8][14].

The role of the teacher in such a setting differs from traditional teaching approaches and asks for pedagogies that foster students' construction of their knowledge through inquiry, exploring, explaining, modelling and finding their own path to effective solution [4][23]. The teacher serves as facilitator, working with student groups if they need help and addressing class-wide problems when necessary [10]. He/she also supports collaborative and cooperative work, during which students work together on inter/intra connected, and challenging tasks. Here, the teacher's role includes [3][23]:

- A guidance of students towards questions and problems of interest for them that contain interesting learning potential.
- Making constructive use of students' prior knowledge.
- Supporting and guiding when necessary their autonomous work.
- Managing small group and whole class discussions.
- Encouraging the discussion of alternative viewpoints.
- Helping students to make connections between their ideas and relate these to important scientific concepts and methods.

In this setting, students are not left alone in their discovery, but are guided by the teacher who supports them in learning to work independently. Inquiry-based methods have been used extensively in the sciences [2][3][5][7][9][20][24] and to a lesser extent in technology and engineering [16][25].

Well-designed inquiry-based learning environments can enhance students' learning experiences [13][17][26]. Blumberg [27] and Magnussen [17] argue that inquiry can improve critical thinking and information processing skills. They state that inquiry tends to improve students' self-regulated learning abilities, but optimal guidance during instruction has to be provided for effective IBL [6][23]. Spronken and Walker argued that while smaller scale inquiry-based learning activities are useful, particularly to progressively develop research skills, the most substantial benefit in terms of learning outcomes occurred with inquiry courses or degree programmes [5].

To capture as wide a range as possible of IBL outcomes, it was crucial to find evidence that addressed inquiry in the different ways in which inquiry occurs in classrooms as [22][28]:

- Process (self-guided activities);
- Content (rich interaction with the material);
- Context (meaning from experience); and
- Strategy (fluid and reflective processes).

Research showed that just single and linear outcomes/effects of IBL in technology education are investigated, while complex impacts are not known yet. The complex impact of IBL in technology/engineering education may be demonstrated also through technological literacy, through which the learning effects in technology and engineering education have not yet been measured.

This study aimed to measure the effect of the use of IBL in an open learning course in middle school technology education. Effects, such as learning achievement, skills of problem-solving and researching, and critical thinking and decision-making abilities of 13-14-year-old students are demonstrated. Students were organised between inquiry-based instruction (treatment group) and traditional lecture-based instruction (control group) of hydraulic turbine optimisation lesson. The results of this study can help students grasp the nature of technology and engineering education and help the teachers to choose the right mode/level of IBL in compulsory courses as supplementary instruction approach. Against this background, the questions explored in this study are:

- Does IBL enhance learning achievements in technology education measured with the recently developed technological literacy methods?
- How do IBL experiences and understandings relate to desirable outcomes - in particular as related to their development towards technological knowledge construction, scientific research abilities, problem-solving skills, and ability of critical thinking and decision-making?

The study was carried out in the context of considerable international interest in strengthening the role of inquiry and research in the middle school experience, both through provision of open-curricular student activity, and through the development of inquiry-based learning pedagogies within the curriculum.

DESIGN AND METHODS

The aim of this section is to set up a conceptual model of IBL for the implementation of large-scale IBL open learning courses. Therefore, material on IBL model design, conceptual framework and learning objectives, students' activities, learning environment and material, research design with student sample, instrumentation, and procedure of data collection and analysis are presented.

IBL Model Design

The study stems from an international multi-institutional research project in which the use of IBL is examined in open learning courses of physics and technology education in Slovenia. To design an IBL activity model, some limitations are considered. The frameworks of 7E [8] and 4E X 2 [3] models are used. To improve metacognitive reflection, some new phases of learning are upgraded and modified as shown in Figure 1. Metacognitive reflection learning becomes central in all stages of inquiry in this model, instead of only in the latter stages of the process. Marshall et al argue that when metacognitive reflection and formative assessment are integrated in IBL, teaching becomes more informed and students have more opportunities to monitor their progress in relation to intended goals [3].

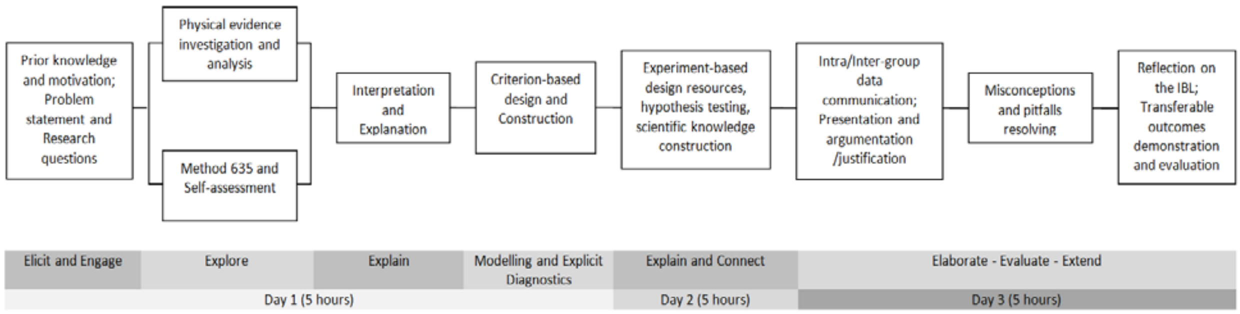

Figure 1: IBL activity diagram-hydraulic turbine optimisation.

Existing models of IBL were upgraded with the phase modelling and explicit diagnostics, in which students have been engaged in experiment design and construction in order to enlarge the usability of existing experiments. They realised that no optimal solutions exist, neither optimal resources nor equipment.

Conceptual Framework and Learning Objectives

An IBL method was embedded in an introductory middle school open learning course titled *Technology Days*. This course is offered within the compulsory programme in middle school around Slovenia. An IBL was conducted in real life classrooms and laboratories, with two technology teachers as instructors. IBL activities were three days long (5 hours a day) with the break period of 3-6 weeks, depending on the school plan.

During the first learning activity day, students:

- were engaged in IBL;
- were given broad physical resources (teacher, materials, data and other sources) to investigate and analyse;
- were given a partial way to formulate explanation and select from other possible ways to formulate explanation;
- designed and constructed the real-life experiment based on criteria which were given by teacher.

During the second IBL activity day, students:

- performed experiments, where they could control one given parameter while others remain constant;
- were directed to other resources and shown how to form links to scientific knowledge;
- were encouraged to collaborate/cooperate with other students;
- tested their own hypothesis using data also collected by other groups.

Day 3 of IBL activity aimed for:

- communication skills development (elaboration, inter/intra group communication);
- critical thinking and decision-making abilities development (presentation, justification of explanation);
- self-assessment and formative assessment of work done (inter/intra groups);
- searching for competitive and transferable outcomes and their potential exploitation.

Cognitive learning outcomes were measured/benchmarked against the following learning objectives:

1. Water energy is the most important renewable energy source.
2. The exploitation of hydro power needs hydraulic machines/turbines.
3. A water source has a definite net head and discharge. Given the aforementioned characteristics a range of hydraulic machines is selected.
4. Hydraulic turbine converts the energy of water (potential, kinetic) into mechanical work.
5. Water at higher level flows through the pipe and, then, flows into the nozzle through a rotor that is tangential to the turbine, where it intercepts the radial attached rotor blade, is split into two symmetrical portions, and it changes direction by almost 180°. The result is a concentrated force to a single blade/bucket.
6. Circumferential force acts on the pitch diameter of the rotor, which is a main dimension of the turbine.
7. Circumferential force depends on the volume flow rate, streaming through the nozzle, and speed of the rotor.
8. Efficiency of the turbine is defined as a ratio of the mechanical output power and hydraulic input power.
9. The efficiency of the turbine will be higher if:

    - the blades are arranged in a ratio, which allows contact with a water jet sequentially;
    - the shape of the blade will be semi-circular that leads the water without losses due to mixing, friction and hitting to nearby blades;
    - the blade size/cross section is in proportion to the diameter of the jet/nozzle;
    - the wheel speed at the pitch diameter is about the half of the jet velocity through the nozzle;
    - the blade attacked angle will be around 90° - perpendicular to a water jet;
    - the inflow of water to the blades is tangential to the rotor with the position of the nozzle against the lowest point of the wheel at pitch diameter.

Students' Activities

The entire activity consists of related components; where the use of various forms of learning occurs to achieve the objectives effectively. Students could work in a number of groupings during this activity. Learning was carried out as presented Table 1.

Table 1: Learning forms at IBL of hydraulic turbine optimisation.

Activity phase	Learning form
Preliminary presentation and engagement.	Frontal form, whole class, teacher led-introduction.
Inclusion hypothesis/research questions.	Individual and in groups/team works, discussion.
Study and analysis of physical evidence.	Small groups of 3-4 students, method of 635.
Interpretation and explanation of data.	Small groups of 3-4 students and discussion/collaborative learning.
Hydraulic turbine design/construction.	Small groups of 3-4 students/collaborative work-based learning.
The research and testing hypotheses.	Small group of 3-4 students, group-based learning, panel discussion.
Data flow between and/or within the groups.	Individual, opinion leader, creative team-work, elevator talk.
Record findings/reporting.	Individual/groups.
Reflection and extension.	Individual/groups.

Learning processes were based on work/study in small groups of 3-4 students where students/groups investigated existing models and, then, conceived/designed (criteria/parametric) the turbine to achieve the best efficiency. In doing so, each selected/specified parameter (parameter P 1-6) was considered to implement different variations, while keeping the others constant. If this approach was adopted, each group would need to share its findings with the whole class at a plenary session, so that all students could write a full report of the research team's findings. Groups mutually and gradually completed the scientific achievement for optimal values in a generic way. After stabilisation of understanding, each group wrote a synthesis/final report of the findings of operation/influencing parameters. All reports were sent to instructor for the final evaluation.

Learning Environment and Material

IBL was carried out in middle school technology and physics classrooms with contemporary laboratories. The IBL provider assigned all necessary equipment, devices, tools, and other sources for effective and safety learning-based work. Teachers and students were given all necessary resources including pupil research briefs (EUPRB). The EUPRBs are resources designed to support the teaching and learning of science through an inquiry-based approach. The EUPRBs provide opportunities for investigative work, with some offering the opportunity for practical investigations. Each IBL provider had prepared their own EUPRB topic, where subject matter knowledge, general pedagogical knowledge, pedagogical content knowledge and knowledge of the context was included. An example of a worksheet for students in Group 2 that investigated parameter P2 (blade size) variations is shown in Figure 2, while a mechanism of the IBL experiment with all parameters is shown in Figure 3.

Group 2

P2: Blade cross section *S* (mm²) (D_{1r}= 105 mm, D_{2r}= 90 mm; D_0= 120 mm, number of blades z=10, angle α= 36°). Measurements are performed sequentially after first four groups. h_1= 2.3 m, m_1=2-7 kg, m_2=0.05-0.25 kg.

Group 2 constructs/makes two rotors with diameter of D_{1r} and D_{2r}, with slots for blades, angle between blades is 36°, two sets of 2x10 blades must be worked out. (S_1=20x15 and S_5=40x30).Data from Group 1, 5, and 6 must be written in the table by cross-examination (study).

Blade size S [mm²]	Measurement preformed by	Measurements M				Turbine system efficiency η
		M_1 h_2 [m]	M_2 h_2 [m]	M_3 h_2 [m]	mean M $\bar{h}_2$ [m]	$\eta = \frac{m_2 \cdot g \cdot h_2}{m_1 \cdot g \cdot h_1} \cdot 100[\%]$
20x15	Group 2					
25x20	Group 1					
30x25	Group 5					
35x30	Group 6					
40x30	Group 2					

Figure 2: Worksheet example for IBL Group 2.

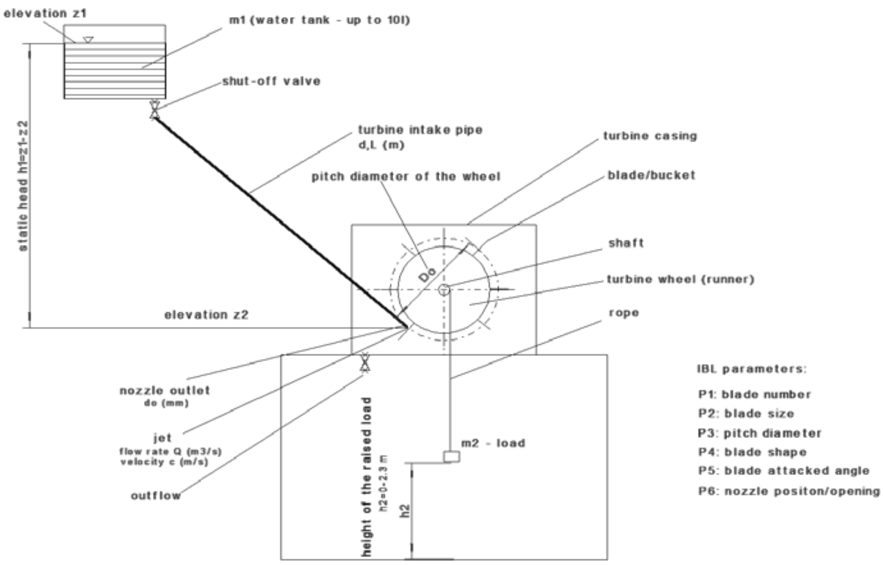

Figure 3: Mechanisms of the experiment at IBL of the hydro turbine optimisation.

Research Design and the Sample

The study design was a two-group pre-test and post-test design that was grounded in the experimental quantitative research tradition. A post-test is a measure of some attribute or characteristic that is assessed for participants in an experiment after a treatment has been provided. This design uses methods to reduce or not violate statistical assumptions, such as normality and homogeneity of variance. Table 2 shows that this study design used two groups: a control group (G_{2C}) and treatment group (G_{1T}). One group received the treatment, in this case, IBL in open learning course of technology education instruction consonant with the research recommendations from the cognitive science perspective on learning and instruction (X), and the control group received no IBL in technology education instruction. Learning outcomes (O) are expressed as a measure of technological literacy.

Table 2: The research design.

Group	Pre-test	Treatment	Post-test
G_{1T}	O_{11}	X	O_{12}
G_{2C}	O_{21}		O_{22}

Variables considered in the study are:

- *Independent:* students (e.g. type of the group, gender) in the treatment and control groups.
- *Dependent:* learning outcomes measured with technological literacy measure (technological knowledge, problem-solving skills and ability to research, critical thinking and decision-making ability).

The sample used in this study was drawn from middle school students. Treatment group students ($n_1 = 91$) were enrolled in the IBL open course of technology education at five middle schools around Slovenia. Control group students ($n_2 = 330$) had no exposure to IBL. They were from six middle schools around Slovenia. IBL was performed from November 2013 to March 2014. The entire course was 3 days long (15 hours), with mid-term breaks of 3-6 weeks between IBL activity days. With the permission of, and assistance from, the parents and instructors who agreed to have their students participate in the study, a paper and pencil pre-test and post-test were distributed. All (n = 421) of the enrolled students completed the test both times. The participants' genders were evenly distributed 50% ($n_F = 211$) females and 50% ($n_M = 210$) males. Students were aged 13-14 years.

Instrumentation

In case of multifaceted nature of technology education measured constructs or phenomena, a holistic method for measurement of technological literacy is proposed [29-33]. For the purpose of this study, a recently developed method for measuring technological literacy was used [34]. This method can be used for measurement of multi-dimensionality of test at the entire scale and of its subscales.

The test items were validated by an expert panel. The experts selected to serve as content validation experts also had participated in the review of the national technology and engineering curriculum, and were university professors and middle school teacher experts. These criteria ensured a deep knowledge of technology/engineering subject matter and pedagogical content knowledge. When the evaluation of survey items was accomplished, the authors have looked for commonalities in the review responses and vetting of undesirable items. The authors examined comments and suggestions and made corrections suggested by the content review experts. A high level of content validity was assured.

Identical versions of the 15-item test were presented at the pre-test and post-test; the test was subdivided into three subscales toward the subject matter (explicit and implicit) of hydraulic turbines, with five items in each subscale: 1) technological knowledge; 2) ability for problem-solving and scientific research skills; and 3) critical thinking and decision-making ability (CTDM). Test items tackle EUPRB hydraulic turbine optimisation, where learning objectives, gained skills and abilities serve as benchmarks. A method for constructing test items is described by Avsec elsewhere [34]. Multiple choice test items consist of a stem and a set of answers/options where the best-answer method was used with dichotomous scoring of alternatives (0 - distracters or 1 - best answer or best combination of answers).

Procedure and Data Analysis

The students participated in the study during normal classroom sessions throughout the school day. The treatment group students participated in IBL in small groups of 3-4 students (6 groups at the level of the class), while the control group had no specific treatment of subject matter except of regular traditional lessons (frontal instruction) in groups up to 25 students in the classroom. At the beginning of each session, the students were instructed to write their names on the pre-test and to complete all test items. Once all students in the treatment group had completed the pre-test, they were engaged in IBL, which included three days of learning activities. Then, the post-tests were distributed to the students and they were instructed to note their name on the post-test and to complete all test items. Administration of the post-test was carried out from December 2013 to March 2014 depending on the school curriculum and activity plan. Post-tests for control group students were administrated in March and April 2014. All post-tests were collected for data analysis.

A high response rate was obtained by the direct presence of teachers/instructors and test administration. Data analysis was conducted using SPSS 21. In case of multi-dimensionality or heterogeneousness of a test, Cronbach's alpha is not suitable as a reliability coefficient [35]. Therefore, test-retest reliability was calculated by comparing the scores of 47 students who filled out the test during the first study (September 2013) and again during the second study (November 2013). The intraclass correlation coefficient (*ICC)* was used as a measure of correlation to contrast with Pearson r correlations. Descriptive analyses were conducted to present the student basic information. The Levene's test for equality of variances was used. Two-way ANOVA was used to find within-subjects contrasts. Multivariate analysis was conducted to find and confirm significant relationships between groups with an effect size. The measure of the effect size is η^2 (eta squared).

RESULTS

Reliability of the test form was assured with test and re-test scores that correlated significantly (Pearson $r = 0.877$, $p < 0.01$). The ICC measure = *0.93 (*$p < 0.01$) depicts strong reliability of the test over time. Correlation analysis of test items revealed that test items were negligibly ($0.01 < r < 0.19$) or weakly correlated ($0.19 < r < 0.29$) [35], because they were measuring different benchmarks.

Overall Pre-post Test Comparisons

All significance tests for the results are two-tailed. Table 3 displays overall descriptive statistics for the pre- and post-tests.

Results indicated a low overall score (the total possible score was 15), which depicts high test item difficulty. The test was designed for longitudinal study of IBL effects in technology education and it is to be used for exploitation during the next two years. The pre-test sample and post-test sample were normally distributed (skewness and kurtosis < 1).

Table 3: Pre-test and post-test statistics.

Test	Group	Frequency	*M*	*SD*	SE_M	Skewness	Kurtosis
Pre-test	Treatment	91	3.02	1.56	0.16	0.32	-0.29
	Control	330	3.12	1.44	0.07	0.45	0.15
	Total	421	3.09	1.46	0.07		
Post-test	Treatment	91	5.03	1.85	0.19	0.41	-0.54
	Control	330	3.22	1.65	0.09	0.67	0.91
	Total	421	3.61	1.85	0.09		

A linear relation between independent (predictor) and dependent (criterion) variables was assumed. It is expected that increases in one variable would be related to increases or decreases in another one. Further descriptive analysis indicated that the test for homogeneity of variance was non-significant, meaning that the sample exhibited characteristics of normality required for analysis under the assumptions of the general linear model. The Levene's test for equality of variances achieved no statistical significance both at pre-test F (1,419) = 3.03 (p = 0.09) and at the post-test F (1,419) = 3.4 (p = 0.07). The Levene's test confirmed that the study sample did not violate the assumption of normality, which confirmed that the sample is normally distributed ($p > 0.05$).

A two-way ANOVA was performed to test within subject contrasts how IBL enhances learning. Statistically significant impacts were found, see Table 4.

Table 4: Tests of within-subjects contrasts.

Source	Test	Type III sum of squares	*df*	s^2	*F*	*p*	η^2
Test	Level 1 vs. Level 2	319.69	1	319.69	308.44	0.00	0.43
Test * Group	Level 1 vs. Level 2	258.83	1	258.83	249.73	0.00	0.38
Error(test)	Level 1 vs. Level 2	434.27	419	1.03			

The groups had significantly ($p < 0.01$) different changes from the pre-test to post-test with a large effect size ($\eta^2 = 0.43$). IBL statistically significant impacts on learning and skills acquisitions ($p < 0.01$) with a large effect size ($\eta^2 = 0.38$). Interaction between the test and group shows that the treatment group statistically significantly improved its performance.

IBL Impact Analysis

In the study of IBL effects (treatment group), score differences in subscales were analysed. Multivariate analysis of variance was conducted that revealed significant impacts of IBL at any dimension/subscale of technological literacy score (knowledge, capabilities, CTDM), Table 5. The increments of IBL achievements were judged to be significant ($p < 0.01$) with a large effect size ($\eta^2 > 0.14$).

Table 5: Tests of between-subjects effects of IBL treatment group.

Dependent variable Increment of	Mean difference $M_{posttest}$-$M_{pretest}$	*SE* of mean difference	Type III sum of squares	df	s^2	*F*	p	η^2
Knowledge	0.98	0.13	89.011	1	89.01	54.50	0.00	0.37
Capabilities	0.69	0.11	43.615	1	43.61	37.96	0.00	0.29
CTDM	0.33	0.07	9.890	1	9.89	17.76	0.00	0.16

IBL Achievements by Student Gender Analysis

Change scores (post-test - pre-test) for whole scale and each subscale on the technological literacy test were computed to compare learning achievement changes of IBL in the treatment group by gender. Two-way ANOVA analysis has shown no significant differences in learning achievements, see Table 6. Male students scored higher in both tests (pre-test $M_{male} = 3.41$, $M_{female} = 2.78$; post-test $M_{male} = 5.34$, $M_{female} = 4.84$).

Table 6: Tests of within-subjects contrasts.

Source	Test	Type III sum of squares	*df*	s^2	*F*	*p*	η^2
Test	Level 1 vs. Level 2	344	1	344	139.97	0.00	0.61
Test * Gender	Level 1 vs. Level 2	0.26	1	0.26	0.10	0.74	0.00
Error(test)	Level 1 vs. Level 2	218.72	89	2.45			

Analyses of variance were conducted on change scores using IBL subscale achievements and student gender as between-subject factors, see Table 7.

Table 7: Tests of between-subjects effects of IBL treatment group compared across the gender.

Dependent variable Increment of	Mean difference $(M_{posttest}-M_{pretest})$ *M* $(M_{posttest}- M_{pretest})$ *F*	*SE* of mean difference	Type III sum of squares	df	s^2	*F*	p	η^2
Knowledge	-0.03	0.27	0.02	1	0.02	0.01	0.92	0.00
Capabilities	-0.15	0.23	0.49	1	0.49	0.42	0.52	0.01
CTDM	0.07	0.16	0.10	1	0.10	0.18	0.67	0.00

The ANOVA indicated no significant main effect of IBL experience on the changes in technological literacy (knowledge, capabilities, CTDM) across the gender, F (1,89) < 1. The treatment group members have improved their achievements evenly.

DISCUSSION AND CONCLUSIONS

The research findings from the present study reveal the importance of IBL design and performance in technology education. It was found that IBL enhancement of learning achievements in technology education was statistically significant with a large and positive effect size. The technological literacy measurement method proved to be a reliable and valid method for measurement of multi-dimensional or heterogeneous tests at the entire scale and over its subscales.

The model of IBL presented in this study has positive effects on the learning achievement development. A large and positive effect size was found in technological knowledge development (η^2 = 0.37), in research skills and problem-solving abilities increase (η^2 = 0.29) and CTDM development (η^2 = 0.16). Results revealed a solid and guided IBL model of open learning course with the largest impact in the knowledge component.

Research on gender differences in IBL indicates no statistically significant implications/ways where some group may be particularly effective. It was also found that both males and females consider all available information while they attune to IBL. A model of IBL hydraulic turbine optimisation suits males and females equally.

The effects of the use of the IBL model presented in this study indicate the possibility of the conceptualisation and instructional practice of IBL in technology education.

The practical implications of this study are that both teachers and course designers should pay attention to the IBL design and organisation given that teachers guidance, structured material, experimental and collaborative work with combination of different didactic methods and learning styles substantially contribute to student learning achievements.

Further research is required to replicate these findings amongst other samples, and to identify whether there are specific variations in IBL practices and styles that are particularly salient to the development of research skills and problem-solving, and critical thinking and decision-making abilities. However, the question of the breakeven point of the teacher's guidance in IBL, which affects students' learning remains unanswered.

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