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Effectiveness of Inquiry-Based Learning: How do Middle School Students Learn to Maximise the Efficacy of a Water Turbine?*

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Inquiry-based learning (IBL) is an inductive pedagogy that best 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. In IBL, students' self-directed learning is centred on multi-parametric problems that do not have a single correct answer, but they need to find the most desirable behaviour/attitude. Therefore, clear evidence of IBL heterogeneous learning achievements measurement, based on reliable and valid instrument, is still lacking. This paper describes the design and experience of the new student-centred IBL model of open learning at the technology education course, which enables a high level of active self-directed learning. In a treatment group were ninety-one students who experienced IBL in a three-day course activity, while in the control group were three hundred and thirty students. Identical forms of technological literacy tests were carried out as pre- and post-tests. Quantitative research methodology was used to analyse the collected data. The multifaceted nature of IBL and its impact were successfully measured with a technological literacy test. The findings of this study showed that IBL is an effective teaching approach in technology education. The effect size was judged to be large and positive in technological knowledge acquisition, in problem-solving skills development, and in critical thinking and decision-making abilities development. A proposed model suits both females and male students equally. Therefore, a high possibility exists for the use of the new IBL model for technology education.

Keywords: inquiry-based learning; water turbine optimisation model; technological knowledge; problem-solving and research skills; critical thinking and decision-making ability; self-directed learning

1. Introduction

Inquiry-based approaches to learning have a long and strong tradition, especially in science education. They are one of many instructional approaches that situate learning in a meaningful task, such as case-based instruction, project-based learning, and research-based learning. Psychological research and theory suggest that by having students learn through an inquiry, they can learn both content and thinking strategies. Students work in collaborative and cooperative groups to identify what they need to learn in order to solve a problem, to gain research skills, and to enhance trade-off capacity. The effectiveness of active learning approaches is still a matter of debate at all level of education [1]. Over the last several decades, conventional explicit instruction has been increasingly supplanted by approaches that are 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 [2]. Inquiry-based learning (IBL) is well suited to helping students become active learners because it situates learning in real-world problems and makes students responsible for their learning. It has the dual emphasis of helping learners develop strategies and construct knowledge. Allowing students to interact with materials, 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 [3]. The IBL in technology/engineering education was very attractive in the 1960s and early 1970s. Together with hands-on experience learning, they formed a basic instructional model [4]. During the last decades, even over several models of IBL, a lack of valid and reliable quantitative measurement of IBL achievements has been detected [3–7]. Teachers had no real-basis feedback, and therefore their instruction approach was moved towards project-based learning as an effective inductive learning strategy in technology and engineering education [8].

A research of IBL impacts on learning is timely because issues of flexible thinking and lifelong learning have come to the fore in discussions of classroom reform. IBL is of increasing interest to science and technology educators as demonstrated by widespread publication of books written about IBL. Educators are interested in IBL because of its emphasis on active, transferable learning and its potential for motivating students. The last efforts of

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many researchers [8–16] caused the IBL to be attractive and effective, especially in science, while in technology/engineering education the IBL effectiveness is still not stable. In addition, IBL has been recommended in science as a leading instructional strategy, while in technology education several limitations exist [8, 14, 17]. Limitations have been focused around instructional material, didactic methods and process planning, assessment, and motivating/learning strategies related to the level of guidance during an inquiry. Until now, no model of IBL in middle school technology/engineering education has been tailored appropriately to be judged as a statistically significant enhancement of learning with a measurable size effect.

1.1 Inquiry-based learning

IBL is a learner-centred approach that emphasises higher order thinking skills [10, 11], and can strengthen the links between teaching and research [5, 6]. Critical thinking, problem-solving skills, and communication skills are more important than simply knowing the content itself [9, 18]. 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 the light of experimental evidence; using tools to gather, analyse and interpret data; proposing answers, explanations and predictions; and communicating the results [19]. Inquiry requires: identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. 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 [19]. It may take several forms, including analysis, problem solving, discovery and creative activities [20].

IBL begins when students are presented with questions to be answered, problems to be solved, or a set of observations to be explained [8]. An important part of this cycle is identifying knowledge deficiencies relative to the problem/question/observation. These knowledge deficiencies become what are known as the learning issues that students research during their self-directed learning. Following self-directed learning, students apply their new knowledge and evaluate their hypotheses in the light of what they have learned. At the completion of each problem/task, students reflect on the abstract knowledge acquired. The teacher helps students to learn the cognitive skills needed for the inquiry, problem solving and collaboration. Because students are self-directed, managing their learning goals and strategies to solve IBL's ill-structured problems/tasks (those without a single correct solution), they acquire the skills and capacity of critical thinking and decision-making needed for lifelong learning [21].

IBL 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 [21]. Inquiry learning is a form of inductive learning, where progress is assessed by how well students develop experimental and analytical skills rather than by how much knowledge they possess [4, 6]. 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 [22, 23].

Several types of IBL 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 on learning, and its scale (within-class, within-course, whole-course, whole-degree) [6]. All models of IBL emphasise the following levels of inquiry that differ from one another in significant ways [9–12, 19, 24]:

- 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 [8] makes a similar distinction between *teacher inquiry,* in which the teacher poses questions, and *learner inquiry,* in which questions are posed by the students. 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 towards formulation of their own conclusions [9, 15].

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, exploration, explaining, modelling, and finding their own path to an effective solution [5, 24]. The teacher serves as facilitator, working with student groups if they need help and addressing class-wide problems when necessary [11]. He also supports collaborative and cooperative work, during which students work together on inter/intra connected and challenging tasks. Here, the teacher's role includes [4, 24]:

- 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 their autonomous work when necessary;
- 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 a teacher who supports them in learning to work independently. Inquiry-based methods have been used extensively in the sciences [3, 4, 6, 8, 10, 21, 25], and to a lesser extent in engineering [17, 26].

Well-designed IBL environments can enhance students' learning experiences [14, 18, 27]. Blumberg [28] and Magnussen [19] 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 [7, 24]. Spronken and Walker [6] argued that while smaller scale IBL activities are useful, particularly to progressively develop research skills, the most benefit in terms of learning outcomes occurred with inquiry courses or degree programmes. Improvement of transferable skills, such as teamwork and independent-learning, problem-solving skills in a real-life situation can hopefully improve critical thinking and problem solving and discharge time pressure in other technology/ engineering courses [29].

To capture as wide a range as possible of IBL outcomes, evidence is found that addressed inquiry in the different ways in which inquiry occurs in classrooms—as process, content, context and strategy [23, 30]:

- Process-activities are guided by learners' curiosity and interests, through which the students learn processing skills (e.g., critical thinking) that can be generalised across subject domains.
- Content-active investigations, critical thinking, and reflection provide opportunities for rich interaction with the material; thus, students achieve a deep understanding of the content and become better able to apply knowledge.
- Strategy-problem-solving, planning, organisational and self-regulation strategies endow students with the skills to carry out self-guided and collaborative investigations. Fluid and reflective processes are used, rather than linear, cook-book approaches.
- Context-learners take meaning from experience. Thus, an inquiry environment requires multiple forms of resources, access to data, individual as well as group activities, dialog, and reflection.

Research showed that only single and linear outcomes and/or effects of IBL in technology education are investigated, while complex impacts are not yet known. Complex acting of IBL in technology/ engineering education may also be demonstrated through technological literacy, where the learning effects in technology and engineering education are not yet measured.

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 IBL pedagogies within the curriculum.

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

Against this background, the questions explored in our study are:

1. Does IBL enhance learning achievements in technology education measured with the recently developed technological literacy method?
2. How does the proposed new model of IBL relate to desirable outcomes—in particular as related to their development towards technological knowledge construction, research abilities, problem-solving skills, and the ability for critical thinking and decision-making?

In the next section, the design, learning environment and performance of the newly proposed IBL model are described. Thereafter, the methodology, which includes the sample, instrumentation, procedure and data analysis, of this study is described. Then, the results are reported and the study is critically discussed. In the concluding section, answers to the research questions are formulated.

2. Design of the new IBL model

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, IBL model design, conceptual framework and learning objectives, students' activities, learning environment and material are presented.

2.1 IBL model

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 [9] and 4E × 2 [4] models are used. To improve metacognitive reflection some new phases of learning are upgraded and modified, Fig. 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. [4] argue that when metacognitive reflection and formative assessment are integrated into IBL, teaching becomes more informed and students have more opportunities to monitor their progress in relation to intended goals.

Existing models of IBL were upgraded and modified within the phase Modelling and Explicit diagnostics, where students were engaged in the experiments' design and construction in order to enlarge usability of existing experiments. They realised that no optimal solution, neither optimal resources nor equipment, exist.

2.2 Conceptual framework and learning objectives

An IBL method was embedded in an introductory middle school open learning course entitled 'Technology Days'. This course is offered within the compulsory programme in middle schools around Slovenia. An IBL was conducted in real-world classrooms and laboratories, with two technology teachers as instructors. IBL activities lasted three days (5 hours a day) with the break period of 3–6 weeks, depending on the school plan. Learning-based work was ignited and controlled by role models.

During learning activity day 1, students:

- were engaged in IBL;
- were given broad physical evidence (teacher, materials, data and other sources) to investigate and analyse;
- were given a partially way to formulate explanations and select from other possible ways to formulate explanations;
- were given the basis of the experiment;
- designed and constructed the real-world components (rotors, blades) for the multi-parametric experiment, based on criteria which are given by the teacher.

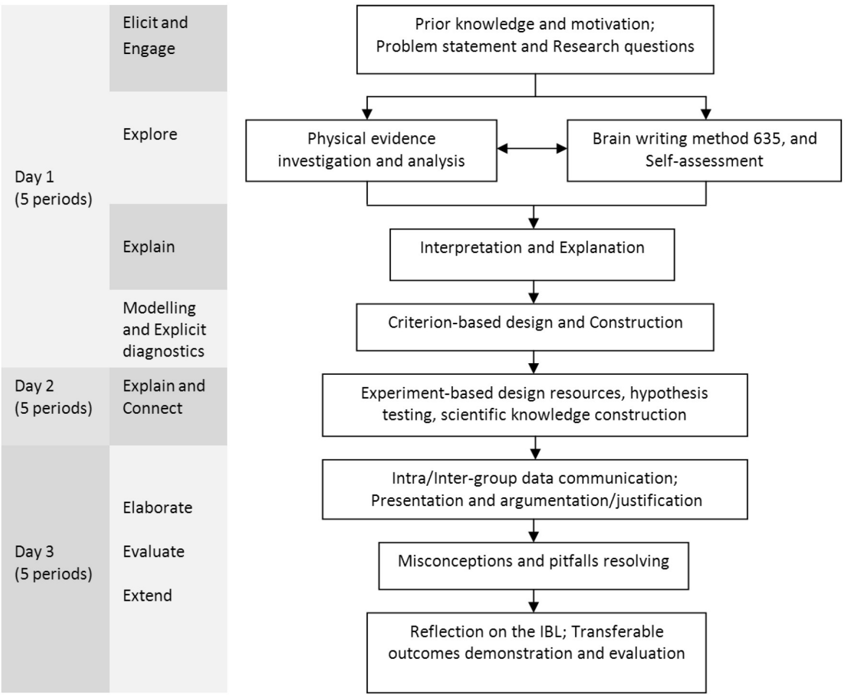


Fig. 1. IBL activity phases—water turbine optimisation.

On the second IBL activity day, students:

- performed experiments that gave control over one given parameter while others remain constant;
- were directed to other options and shown how to form links to scientific knowledge;
- were encouraged to collaborate/cooperate with other students;
- tested their own hypotheses, also using data collected/acquired by other groups.

Day 3 of IBL activity was aimed at:

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

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

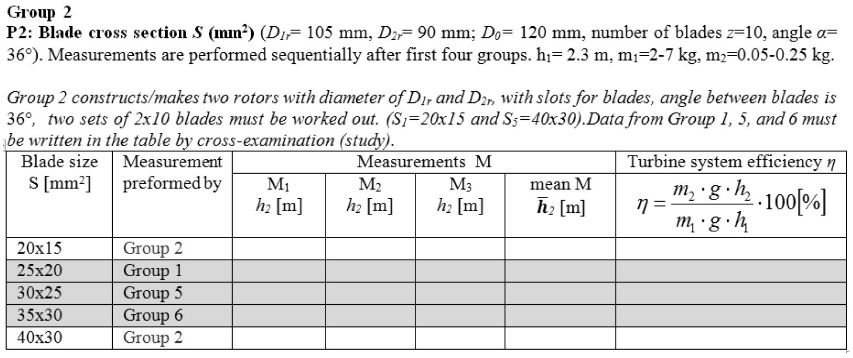
1. Water energy is the most important renewable energy source.
2. The exploitation of hydro power needs hydraulic machines/turbines.
3. The water source has a definite net head and discharge. Given the aforementioned characteristics, a range of hydraulic machines is selected.
4. The hydraulic turbine converts the energy of the water (potential, kinetic) into mechanical work at its shaft.
5. Water at a higher level flows through the pipe and then flows into the nozzle through a tangent to the rotor of the turbine, where it intercepts the radial attached rotor blade, it is split into two symmetrical portions, and it changes the direction by almost 180º. The result is a concentrated force on a single blade/bucket.
6. A circumferential force acts on the pitch diameter of the rotor, which is a main dimension of the turbine.
7. A circumferential force depends on the volume flow rate, streaming through the nozzle, and the speed of the rotor.
8. The efficiency of the turbine is defined as a ratio of the mechanical output power and hydraulic input power.
9. The efficiency of the hydraulic turbine will be higher if:
    - the blades are arranged in a ratio that allows contact with a sequential jet;
    - the shape of the blade will be semicircular, which leads the water without a loss due to mixing, friction, and hitting the nearby blades;
    - the blade size/cross-section is proportional to the diameter of the jet/nozzle;
    - the wheel speed at the pitch diameter is about the half the jet velocity through the nozzle;
    - the blade attack angle will be around 90º–perpendicular to the water jet;
    - the inflow of the 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.

2.3 Students' activities

The entire activity consists of related components where the use of various forms of learning effectively achieve the objectives. Students could work in a number of groups during this activity. All the approaches emphasise that learners are actively constructing knowledge in collaborative groups. The roles of the student and teacher are trans-

Table 1. Learning forms at IBL of hydraulic turbine optimisation

Activity day	Activity phase	Learning form/style
	Preliminary presentation and engagement.	Frontal form, whole class, teacher led-introduction.
Day 1 (5 hours)	Inclusion hypothesis / research questions.	Individual and in group/team work, discussion.
	Study and analysis of physical evidence. Multi-parametric problem solving.	Small groups of 3–4 students, Brain writing method of 635.
	Interpretation and explanation of data/ info.	Small groups of 3–4 students and discussion/collaborative learning.
	Experiment modification and upgrade. Hydraulic turbine design/construction.	Small groups of 3–4 students /collaborative work-based learning.
Day 2 (5 hours)	The research and testing hypotheses.	Small group of 3–4 students, team/group-based learning, panel discussion, flipped learning.
	Data flow between and/or within the groups.	Individual, opinion leader, creative team work, elevator talk.
	Record findings /reporting.	Individual/groups.
Day 3 (5 hours)	Reflection and extension.	Individual/groups.
	Peer-assessment/external evaluation.	Pairs, peers, groups; Role model.



Group 2

P2: Blade cross section S (mm^2) (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 [mm^2]	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					

Fig. 2. Worksheet example for IBL Group 2.

formed. The teacher is no longer considered the main repository of knowledge; he is the facilitator of collaborative learning. In IBL, students become responsible for their own learning, which necessitates reflective, critical thinking about what is being learned. In IBL, students are asked to put their knowledge to use and to be reflective and self-directed learners. Learning was carried out, Table 1.

The learning process based on the work/study in small groups of 3–4 students where students/groups were investigating existing models and then conceiving/designing (criteria/parameters) the turbine to achieve the best efficiency. In doing so, each selected/specified parameter (parameters P1–6) is considering to implement different variations while keeping the others constant. If this approach is adopted, each group needs to share its findings with the whole class at a plenary session so that all students can write a full report of the research team's findings. Groups mutually and gradually complete the scientific achievement for optimal values in a generic way. After stabilisation of understanding, each group writes a final report of the findings of the operation/influencing parameters. All reports were sent to the instructor/role model for final evaluation.

2.4 *Learning environment and material*

IBL was carried out in middle school technology and physics classrooms with contemporary laboratories. The IBL provider assigned schools to provide all necessary equipment, devices, tools, and other sources for effective and safe learning-based work. Teachers and students are given all necessary resources, including student research briefs (EUPRB). The EUPRBs are resource 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 (role model) had prepared their own topic in EUPRB, where subject matter knowledge, general pedagogical knowledge, pedagogical content knowledge, and knowledge of the context are included. An example of a worksheet for students in Group 2 who investigated parameter P2 (blade size) variations is shown in Fig. 2, while a mechanism of the IBL experiment with all research parameters (P1–6) is shown in Fig. 3.

Students in Group 2 first made an experimental prototype of a water turbine, Fig. 3, which was tested in the laboratory. Students tried to find ways of getting the maximum efficiency by varying blade size, while other parameters remained constant. Students in Group 2 did not test all range of blade size variations, because our IBL model also claims for cooperative learning. Thus, they realised that some data can also be provided by the other groups or data sources. These data present a data source for a worksheet shown in Fig. 2, and the benchmarks for one's own measurements (calibration). Each IBL group collaborated and cooperated with others in order to carry out effective inquiry. Groups 1, 5 and 6 illustrated and shadowed in the worksheet in Fig. 2, were data providers for missing measurements and served as external evaluators of the measurements. When the worksheets of each group were finished, all depicting data were summarised in a graph to find the best efficiency point on the efficiency curve.

Students were actively doing things: solving the multi-parametric problem (key parameter spin-offs), designing the turbine system, creating their own experiments, and measuring parameter variations and their impacts. The advisor is encouraging and keeps a focus on what they are doing. Students were: evaluating the problems; employing metacognition to understand not only what was learned (technological knowledge) but how it was learned (transferable skills) and how (why) this fits into future learning needs (critical thinking and decision-making); advisor models self-analysis; interpretation and explanation.

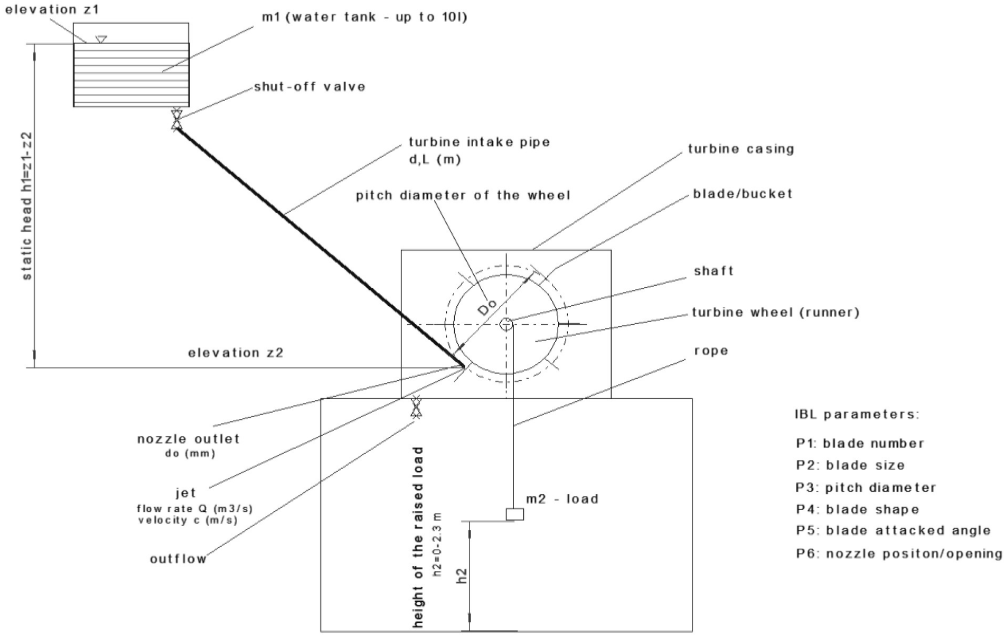


Fig. 3. Mechanisms of the experiment of the hydro turbine optimisation at IBL.

3. Methods

In the following sections, the research design with the student sample, instrumentation, and procedure of data collection and analysis are described.

3.1 Research design and the sample

An experimental study is used as a type of evaluation that seeks to determine whether an IBL had the intended causal effect on program participants. There are three key components of an experimental study design: (1) pre–post test design, (2) a treatment group and a control group, and (3) assignment of study participants. 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 a treatment group (G_{1T}). One group received the treatment, in this case, IBL in the 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, who received no IBL in technology and engineering education instruction. Learning outcomes (O) are expressed as a measure of technological literacy.

Table 2. The research design with three key components

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

The variables considered in the study are:

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

The sample in this study was drawn from middle school students. Treatment group students (N_1 = 91) were enrolled in an IBL open course of technology education at five middle schools around Slovenia. Control group students (N_2 = 330) had no treatment of IBL. They were from six middle schools around Slovenia. IBL was performed from November 2013 to March 2014. The entire course lasted 3 days (15 periods), 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 accordingly. All ($N = 421$) of the enrolled students completed the test both times. The participant's genders were evenly distributed 50% (N_F = 211) females and 50% (N_M = 210) males. Students were aged 13–14 years.

3.2 Instrumentation

In the case of a multifaceted nature of a technological education measured construct or phenomena, a holistic method for the measurement of technological literacy is proposed [31–35]. For the purpose of this study, recently developed method for measuring technological literacy [36] was used. Method can be used for the measurement of multi-dimensionality of the test over the entire scale and of its subscales.

The test items (TI) 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 teaching experts. These criteria ensured a deep knowledge of the technology/engineering subject matter and pedagogical content knowledge. When the evaluation of survey items was accomplished, we looked for commonalities in the review responses and vetting of undesirable items. We 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 pre-test and post-test; the test was subdivided into three subscales towards 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; (3) critical thinking and decision-making ability (CTDM). TI tackles EUPRB Hydraulic turbine optimisation, where learning objectives, gained skills and abilities serve as benchmarks. The method for TI construction is described in [36]. Multiple-choice TI consists of a stem and a set of answers/options where the best-answer method was used with dichotomous score of the alternatives (0–distracters or 1–best answer or best combination of answers).

The technological knowledge TI example to measure student achievement is as follows:

A water turbine:

A: exploits hydraulic power
B: converts the energy of the water into mechanical work at its shaft
C: converts the kinetic energy of the water into electrical energy at the generator
D: uses the potential and kinetic energy of water.

An example of TI to measure the achievement of problem-solving and research skills is as follows:

You want to design and construct a water turbine, but a lack of the data is detected. Where (how) do you find the most reliable and valid data, and why?

A: I have to ask parents and friends.
B: I have to read about on Wikipedia.
C: I have to ask a teacher.
D: I have to read the scientific paper.
E: I have to design my own experiment at home.

Reason:
1: They know a lot and are willing to help.
2: Data are scientific and reliable.
3: Data are verified and valid.
4: He is a reliable person.
5: It can provide a bundle of data.

An example to measure critical/logical thinking and decision-making capacity is as follows:

Luke creates a water turbine. He has already constructed a wheel (rotor) with a pitch diameter of 120 mm. The calculated number of blades is 10, and a blade cross-section is 500 mm^2. But he does not know the form/shape that the blades should be. It offers six different shapes: plain, triangular, rectangular with bend short tabs, rectangular with bend long tabs, triangular with bent tabs, and a semicircular curved tab (bucket). Which shape needs to be selected so that his turbine will provide better efficacy and why?

A: plain
B: rectangular with tabs
C: rectangular with long tabs
D: triangular or rectangular
E: semicircular

Reason:
1: a water jet strikes just a single blade
2: no water lost due to bending
3: a water flow can cycle in the blade
4: outflow energy is reduced
5: water flow may impact also on the bottom blades

3.3 Procedure and data analysis

Students participated in the study during natural classroom sessions throughout a school day. The treatment group students were participating at 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 the subject matter, except for regular traditional lessons (frontal instruction) in groups of up to 25 students in the classroom. At the beginning of each session, students were instructed to write their names on the pre-test and to complete all TI. Once all the students in the treatment group had completed the pre-test, they were engaged in IBL, which had three days of learning activities. Then, the post-test were distributed to the students and they were instructed to note their name on the post-test and to complete all TI. Administration of the post-test was carried out from December 2013 to

March 2014 depending on the school curriculum and activity plan. The post-test for the control group students was administered in March and April 2014. All post-tests were collected for data analysis.

The high response rate was obtained by the direct presence of teachers/instructors and test administration. Data analysis was conducted using SPSS 21. In the case of multi-dimensionality or heterogeneousness of a test, Cronbach's alpha is not suitable as a reliability coefficient [37]. 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 the Pearson r correlations [38]. To support the criterion-related validity of the test, the corrected Pearson r_{xy} coefficient was used. The Pearson corrected coefficient, r_{xy}, is an appropriate measure of criterion-related validity [39, 40]. It served us both to verify the concurrent and predictive validity [40].

A two-way mixed effect model (absolute agreement definition) was used. Descriptive analyses were conducted to present the basic student information. The Levene test for equality of variances was used. A 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).

4. Results

Middle schools, which have been recruited in this study, were selected by IBL role models (scientist from university, applied science researchers, young researchers). The study was carried out at the following Slovenian middle schools, Table 3. All students had a homogeneous structure and a similar demographic situation. There were between 500 and 800 students at each elementary school. Schools are mostly located in major urban areas or urban centres.

Reliability of the test form was assured with test and retest scores that correlated significantly (Pearson $r = 0.877$, $p < 0.01$). Measure of the intraclass correlation $ICC = 0.93$ ($p < 0.01$) depicts a strong reliability of the test over time. The balance of the variance ($1—ICC = 0.07$) is attributable to error. A high *ICC* provides a minimum number of misclassifications at the measurement of heterogeneous and complex nature of construct [38].

A correlation analysis was run to determine if the TI were not correlated to each category/subscale and/or benchmarks. Test categories were distributed as subscales: (a) knowledge (TI1–3, TI9, TI15); (b) capabilities (TI4, 5, 7, 8, 10); (c) CTDM (TI6, 11, 12, 13, 14). Correlation analysis of TI revealed that there were no TI or they were negligible ($0.01 < r < 0.19$), and weakly correlated ($0.19 < r < 0.29$) [37] because they were measuring different benchmarks, Table 4.

A low value of the Pearson correlation coefficient $r_{xy} < 0.29$, Table 4, demonstrates that all TI are designed and constructed very solidly and each TI measures exactly what it is designed for. Thus, we avoided the overlapping of TI with each other. An evidence of high criterion-based validity is provided and, thus, a high concurrent and predictive validity of the results is verified [40].

4.1 Overall pre-post test comparisons

All significance tests for the results are two-tailed. Table 5 displays the overall descriptive statistics for the pre- and post-tests. The descriptive data and the comparison of measurements of the central tendency show that the 13–14 year old students taking IBL scored higher on the technological literacy test *(* $M = 5.03$, $SD = 1.85$) than those who had no previous IBL exposure. They had a mean of

Table 3. Students' numbers through the treatment group (1) and control group (0)

School name	Group	Male [number]	Female [number]	Total [number]
1. Kette-Murn, Ljubljana	1	3	15	**18**
2. Mokronog	1	6	12	**18**
3. I. C. Vrhnika	1	10	8	**18**
4. D. J. Cerklje na Gorenjskem	1	4	12	**16**
5. A. T. L. Radovljica	1	12	9	**21**
6. Brestanica	0	13	15	**28**
7. I. G. Škofja Loka	0	24	20	**44**
8. S. K. Sežana	0	31	32	**63**
9. M. P. Črnuče	0	38	40	**78**
10. Sostro	0	24	23	**47**
11. S. Ž. Kranj	0	45	25	**70**
Total		**210**	**211**	**421**

Table 4. Criterion-related validity test with calculated correlations between TI (TI1–15), using corrected Pearson coefficient r_{xy} ($n = 421$). Correlations $r_{xy} > 0.12$ are significant at the $p = 0.01$ level (2-tailed)

	TI2	TI3	TI4	TI5	TI6	TI7	TI8	TI9	TI10	TI11	TI12	TI13	TI14	TI15
TI1	0.03	0.03	0.01	0.16	–0.01	0.08	0.24	–0.01	0.06	–0.03	–0.01	0.01	0.00	0.02
TI2	–	0.25	–0.03	–0.07	–0.11	–0.01	0.09	–0.01	0.03	0.06	0.02	0.08	0.01	0.08
TI3		–	–0.04	0.03	–0.04	–0.01	0.01	–0.01	–0.03	0.05	–0.03	0.03	0.08	0.01
TI4			–	–0.07	0.01	0.07	–0.03	0.06	–0.05	–0.08	0.00	0.05	–0.01	0.01
TI5				–	–0.01	0.04	0.09	0.04	0.13	0.01	0.04	–0.02	0.01	0.03
TI6					–	0.09	0.05	–0.06	–0.00	–0.01	0.06	0.05	0.04	0.07
TI7						–	0.02	0.06	0.05	–0.00	–0.00	–0.04	0.03	–0.06
TI8							–	0.07	0.00	0.00	–0.01	0.03	–0.02	0.01
TI9								–	–0.03	0.04	–0.01	0.06	0.06	0.07
TI10									–	0.16	0.03	0.15	–0.03	0.00
TI11										–	0.10	0.19	0.10	0.06
TI12											–	0.21	0.02	0.09
TI13												–	0.06	0.10
TI14													–	0.13

Table 5. Pre-test and post-test descriptive statistics of a treatment and control group ($n = 421$)

Test	Group	Number of students	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			

$M = 3.22$, and standard deviation of $SD = 1.65$. The standard error of the mean was acceptable at $SE_M <$ 5%, which supports a high reliability of the sample.

Results indicated a low overall score (max.15), which depicts high TI difficulty. The test was designed for a longitudinal study of IBL effects in technology education and it is anticipated for exploitation in the next two years. Pre-test sample and post-test sample were normally distributed (skewness and kurtosis <1).

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. Further descriptive analysis indicated that the test for homogeneity of variance was insignificant, meaning that the sample exhibited characteristics of normality required for analysis under the assumptions of the general linear model. The Levene test for equality of variances achieved no statistical significance both at pre-test F (1, 419) = 3.03 ($p = 0.09 > 0.05$) and at post-test F (1, 419) = 3.4 ($p = 0.07 > 0.05$). The Levene 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 subjects contrasts how IBL enhances learning in a treatment group. Statistically significant impacts were found, Table 6.

The groups had significantly ($p < 0.01$) different changes from pre-test to post-test with a large effect size ($\eta^2 = 0.43$). IBL is statistically significant and impacts on learning and skills acquisitions ($p < 0.01$) with a positive and large effect size ($\eta^2 = 0.38$).

Table 7 shows the test of between-subjects effects. In our case, this tests if there are significant differences between the two groups. However, this test combines the pre-test and post-test data for all groups. Therefore, for our example, this is a useful test. For example, if the control group scored M = 3.12 on the pre-test and M = 3.22 on the post-test,

Table 6. Tests of the differences in learning achievements within treatment and control group over the time measured with pre- and post-tests with df-degrees of freedom, s^2 – mean square, F–statistics, p – statistical significance, and η^2—effect size ($n = 421$)

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			

*η^2 measure of effect size (from 0.01 to 0.05—a small effect, of 0.06 to 0.14—medium effect, 0.14 and more—large effect).

Table 7. Tests of the differences in learning achievements between treatment and control groups combined pre- and post-test (n = 421)

Source	Type III sum of squares	*df*	s^2	*F*	*p*	η^2*
Intercept	3699.52	1	3699.52	1636.13	0.00	0.79
Group	51.93	1	51.93	22.96	0.00	0.06
Error	947.42	419	2.26			

*η^2 measure of effect size (from 0.01 to 0.05—a small effect, of 0.06 to 0.14—medium effect, 0.14 and more—large effect)

Table 8. Tests of between-subject effects of the IBL treatment group taking into consideration mean differences resulting from post- and pre-tests (n = 91)

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

*η^2 measure of effect size (from 0.01 to 0.05—a small effect, of 0.06 to 0.14—medium effect, 0.14 and more—large effect)

Table 9. Tests of the differences in learning achievements across gender over time measured with pre- and post-tests (n = 91)

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			

*η^2 measure of effect size (from 0.01 to 0.05—a small effect, of 0.06 to 0.14—medium effect, 0.14 and more—large effect)

while the treatment group scored $M = 3.02$ and $M = 5.03$ on the pre- and post-test respectively, then the improvements of the treatment group would show up in the test. We can see in Table 7, that when the pre- and post-tests are combined, the groups are significantly different ($p = 0.00 < 0.05$). The impact on learning is medium ($\eta^2 = 0.06$). Interaction between test and group shows that the treatment group is statistically significant and improved its performance.

4.2 IBL impacts analyses

In the study of IBL effects (treatment group), the score differences in subscales were analysed. Multivariate analysis of variance was conducted that revealed significant impacts of IBL at any dimension/subscale of the technological literacy score (knowledge, capabilities, CTDM), Table 8.

The increments of IBL achievements were judged to be significant ($p < 0.01$) with positive and large effect size ($\eta^2 > 0.14$). The highest increment was surprisingly detected for technological knowledge, which indicates a high ratio of guidance at IBL. A significant collaborative work was detected (transferable skills development) and students became more critical after their IBL experience. TI to measure CTDM components were also proved to be most difficult due to prior ineffective work in the technology class where meta-cognition was not engaged in at a proper scale in the instruction. Schools enrolled in this study provide technology lessons more as traditional learning, with some exceptions of project-based learning for optional subjects of technology/engineering.

4.3 IBL achievements by student gender analyses

Change scores (post-test–pre-test) for the whole scale and each subscale on the technological literacy test were computed to compare learning achievement changes of the IBL in the treatment group by gender. A two-way ANOVA analysis has shown no significant differences in learning achievements, Table 9. Male students scored higher in both tests (pre-test mean of $M_{male} = 3.41$, $M_{female} = 2.78$; post-test of $M_{male} = 5.34$, $M_{female} = 4.84$).

Analyses of variance were conducted on change scores using IBL subscale achievements and student gender as between-subject factors, Table 10.

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

5. Discussion

The main purpose of this study was to investigate whether the CHAIN REACTION project's new

Table 10. Tests of between-subjects effects of IBL treatment group compared across gender (n = 91)

Dependent variable increment of	Mean differences $(M_{posttest}—M_{pretest})_{male}$ – $(M_{posttest}—M_{pretest})_{female}$	*SE* of mean differences	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

*η^2 measure of effect size (from 0.01 to 0.05—a small effect, of 0.06 to 0.14—medium effect, 0.14 and more—large effect)

IBL model enhances student learning in technology and engineering education.

The investigation of the IBL achievements yielded some interesting results. Visual observations of the IBL performance discovered that students have revealed many obstacles causing learning to be ineffective. Students realised that parameters modifications are very sensitive and can produce several misconceptions. The design and creation of real-world components need a great deal of accuracy, motivation, quality of devices, machines and tools, and just-in-time knowledge to produce elements of a high quality. Only well tailored experimental designs can produce reliable, valid and accurate enough results.

The model of IBL presented in this study has positive effects on 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 also increases (η^2 = 0.16). Results revealed a solid IBL model of the open learning course with a surprisingly largest impact in the knowledge component. According to previous research on IBL, the CTDM component was judged to be decisive [18]. This indicates more teacher involvement at IBL sessions.

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.

The following assumptions were made about the study, its context, and the classroom [41, 42]:

- Adapting the methodology of the phenomenon under study and not vice versa.
- The representativeness of the sample population available.
- Providing at least two or more different locations to hold the research.
- A focus only on the individual component of capabilities/skills: the fact is that every student has a variety of abilities (intellectual, mechanical, sensory and motor), which in the classroom are not developed to the same extent in all students, but they demonstrate different competency to act; many of them are very complex (especially in combination) and it is difficult to show clearly. No effect is not sufficiently understood, this can be the basis for the practice of measurement.
- Ensuring the selection of research groups, where there is minimal IBL, but as many different forms and methods of instruction that promote social learning. The fact is that too little attention to the social aspects of learning can be a serious deficiency for measurement capabilities. How students learn depends on their personality traits (temperament, character) and abilities, but also it is different from the content of tasks and situations in which it is located.

This study was conducted in the light of the following three primary limitations:

1. The schools used for this study offered technology education where traditional learning is applied. At all schools, optional subjects of technology education were conducted where the strategy of project-based learning is used. Therefore, students might have different experience with social learning.
2. The data for this study was from a convenience sample of students from schools located in a major urban area.
3. The framework for the IBL model, used in this study, is based on 7E [9] and 4E X 2 [4] models, recommended by the Chain Reaction project.

Other limitations could consist of the quality of the programme, teacher effects, and how the students perform in traditional academic courses.

6. Conclusions

The research findings from the present study reveal the importance of IBL design and performance in technology and engineering education.

Our proposed model of IBL enhances learning achievements in technology and engineering education. A positive large progress in learning was detected in knowledge, capabilities, and critical thinking and the decision-making component. The technological literacy measurement method was proved as a reliable and valid method for measurement of multi-dimensional or heterogeneous tests in a whole and over its subscales.

This IBL design helps students to construct an extensive and flexible knowledge base of water resource exploitation. Results/learning outcomes acquired by IBL allow students to become effective collaborators, co-operators, and become intrinsically motivated to learn. A model of IBL hydraulic turbine optimisation suits males and females equally. Students on site develop effective problem-solving skills and self-directed, lifelong learning skills. Students also realised that interpretation is insufficient to understand phenomena. A reflective explanation connects facts and results with science concepts and makes a prediction for the future behaviour or decision-making. The effects of the use of the IBL model presented in this study indicate the possibility of the conceptualisation and instructional practise of IBL in technology and engineering 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 teacher guidance, structured material, experimental and collaborative work with a combination of different didactic methods and learning styles substantially contributes to student learning achievements.

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

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