World Transactions on Engineering and Technology Education
Vol.16, No.4, 2018

ICT-supported inquiry-based learning

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ABSTRACT: Inquiry-based learning (IBL) is a teaching approach that can enhance student learning outcomes and develop inquiry skills. In IBL, the use of ICT can play a vital role in searching, capturing, analysing and presenting data. In education of future STEM teachers, it is important for the students to experience ICT-supported IBL. The research focused on a course at the second Bologna cycle, in which 18 future STEM teachers developed and implemented seven ICT-supported IBL teaching units. The Spronken-Smith's et al survey instrument was used to determine students' perceptions related to the ICT-supported IBL. The survey was completed by 121 students (age 13-15 years). The results indicate that the majority of students mentioned a perception of a *great deal* or *quite a bit* of positive effects on mental processes in ICT-supported IBL. Regarding students' perceptions of the intended learning processes, they had the greatest impression in *thinking about the purpose of experimental research, solving challenges* and *encouragement to take responsibility for learning*.

INTRODUCTION

Inquiry-based learning (IBL) is a teaching approach that can enhance student learning outcomes, as well as develop inquiry and research skills [1-4] by enabling students to follow the methods and practices of professional scientists in developing their knowledge [5]. Various types of IBL are discussed in the literature and, although according to Furtak et al [3], there is no common agreement about the meaning of the term *inquiry*, Spronken-Smith et al [6][7] suggested that IBL types can be classified as:

- the level of scaffolding;
- the emphasis on learning;
- the scale or duration of the IBL.

Researchers differentiate the following modes of inquiry:

- structured inquiry, where the teacher provides a research problem and outlines an inquiry plan;
- guided inquiry, where the teacher provides only the research problem and pertinent questions;
- open inquiry, where students formulate the research problem and the inquiry phases for themselves [6][8].

Inquiry-based learning enables students to learn assimilate information about a topic through self-directed investigation by progressing through different inquiry phases. The literature describes a variety of inquiry phases and inquiry cycles. An inquiry cycle with five inquiry phases has been proposed by White and Frederiksen viz. *question, predict, experiment, model* and *apply* [9]. However, more recently, the widely used five inquiry phases are in the 5E learning model [10]. This model consists of the following phases: *engagement, exploration, explanation, elaboration* and *evaluation*.

A distinction between these models is that the initial phases of the White and Frederiksen inquiry cycle (question and predict) suggest a theory/hypothesis driven approach. On the other hand, the 5E cycle (engagement and exploration) suggest starting with an empirical data-driven approach [11].

A literature review aiming to identify the core phases of IBL and how the different phases are involved in the learning process revealed five distinct general inquiry phases: *orientation; conceptualisation* including sub-phases questioning and hypothesis generation; *investigation* including sub-phases exploration or experimentation and data interpretation; *conclusion*; and *discussion* including sub-phases reflection and communication [11].

Many studies of IBL focused on learning science, technology, engineering and mathematics (STEM) subjects [12]. The researches point out that IBL provides students an authentic understanding of the nature of scientific knowledge and is a powerful tool for developing scientific thinking strategies, as well as learning with understanding [13].

Researchers conclude that IBL contributes to positive student outcomes in STEM subjects, including knowledge acquisition, development of problem-solving skills, critical thinking and decision-making abilities [3][4][14-18]. Sproken-Smith et al reported that students' perception of learning and intended learning outcomes in IBL courses were well rated [7].

Recent information and communications technology (ICT) advancements enhance IBL [4]. Gerard et al reported a review of professional development in technology enhanced science [19]. They found that comprehensive programmes lasting longer than one year had a significant positive effect on students' IBL experiences. Some more recent reviews have focused on IBL supported by mobile technology [20-22].

Zydney and Warner identified typical settings with mobile apps, i.e. technology-based scaffolding, location-aware functionality, and digital knowledge sharing and construction [21]. Researchers determined that basic scientific knowledge or conceptual understanding were the main outcomes determined by the studies [21]. The shortcomings of mobile technology on IBL are linked to the duration of interventions, the methods of measurement of higher-level skills, and also the weak integration of mobile with learning activities [22].

METHOD

Context

The teacher's role in IBL is to be a facilitator in a self-directed learning environment [23]. With regard to the teacher's role, it is beneficial for future teachers to gain experience with IBL by direct contact with students during their studies at the university. Also, despite the long-standing interest in educational technology reforms, many studies have found that incorporating advanced ICT into classrooms has proven difficult [24]. Therefore, this research focused on a course in the second Bologna cycle (typically Master's level), in which future STEM teachers developed and implemented ICT supported IBL teaching units. The main aim of this study was to investigate students' perception of learning processes and learning outcomes in ICT supported IBL teaching units implemented by future STEM teachers.

The following two research questions (RQ) were defined:

- RQ1: What are the students' perceptions of learning processes in ICT supported IBL teaching units?
- RQ2: What are the students' perceptions of their learning outcomes in ICT supported IBL teaching units?

Research Subjects

The research subjects consisted of 121 students from seven lower secondary schools, aged 13 to 15 years, who participated in one of the seven IBL teaching units supported by ICT. They completed a survey after participation. The participant's sexes were evenly distributed i.e. 50.41% (n = 61) females and 49.59% (n = 60) males.

ICT-supported IBL Teaching Units

The focus of the investigation was a course *Project* and experimental work that took place for two hours a week for 15 weeks from February to May 2018 at the Faculty of Education, University of Ljubljana, Slovenia. Eighteen future STEM teachers in their fourth year of the first Bologna cycle (Bachelor's level) participated. The future STEM teachers developed seven 90-minutes long ICT supported IBL teaching units that were inspired by the possibilities of the use of wireless sensors in chemical experimental work [25].

The future STEM teachers were able to use the teaching units with students from lower secondary schools to receive feedback and gain experience with the implementation of ICT supported IBL in STEM teaching. For this purpose, seven lower secondary schools were contacted and invited to participate in the teaching units in the Faculty of Education at the University of Ljubljana.

The teaching used guided IBL, where groups of three or four students investigated different topics connected with chemistry in everyday life (Table 1).

Each teaching unit started with a preliminary activity, where students gained experience using sensors and a data-collection program on a tablet computer to initiate or advance the study of a specific topic. Further phases were based on the 5E learning model. Activities in which students collected, presented and analysed data were ICT supported by using pH, temperature or gas pressure sensors viz. Go Direct® pH Sensor, Go Direct® Temperature Probe and Go Direct® Gas Pressure Sensor, respectively. The sensors were connected to a data-collection program on a tablet computer viz. Graphical Analysis™ 4.

Activities in which students presented, analysed and discussed results were additionally supported by the use of an interactive whiteboard viz. Promethean ActivBord 300 Pro. The main tasks of the future STEM teachers were to introduce the IBL topic, to circulate among the student groups providing feedback on IBL-phases and to guide the final discussion when student groups presented their IBL research results.

Table 1: Topics for the ICT supported IBL teaching units.

Topic for IBL	Main research questions	ICT used
Yeast fermentation	How do different factors (e.g. temperature, pH) affect fermentation rate?	Gas pressure sensor connected to data-collection program on tablet computer; interactive whiteboard
Energy content of food	How does the energy content of various foods compare?	Temperature sensor connected to data-collection program on tablet computer; interactive whiteboard
Energy content of fuels	How does the heat of combustion of various fuels compare?	Temperature sensor connected to data-collection program on tablet computer; interactive whiteboard
Cold packs	How does the performance of a urea cold pack compare to the performance of an ammonium nitrate cold pack?	Temperature sensor connected to data-collection program on tablet computer; interactive whiteboard
Household products	How does the pH of vinegar change as it reacts with baking soda?	pH sensor connected to data-collection program on tablet computer; interactive whiteboard
Acidification of milk	How does the pH of opened milk change with time?	pH sensor connected to data-collection program on tablet computer; interactive whiteboard
Enzyme activity	How do different factors (e.g. temperature, pH) affect enzyme activity?	Gas pressure sensor connected to data-collection program on tablet computer; interactive whiteboard

Instrument

For this investigation, the Spronken-Smith et al paper-and-pencil survey instrument was adopted to determine students' perceptions of the IBL learning process using ICT [7]. The survey had four sections:

- First - asked students to rate to what degree the teaching unit had encouraged them to engage in activities, such as memorising, explaining, analysing, applying, evaluating/judging, creating and reflecting;
- Second - considered learning processes and asked students to rate their experiences on the course in terms of the type of questions they addressed, whether they were challenged, whether they were encouraged to take responsibility for their own learning, as well as aspects of how they learned;
- Third - asked for open-ended comments about three or four aspects of the course that had been particularly valuable;
- Fourth - collected demographic data.

Data Collection and Data Analysis

To evaluate the student's perceptions of learning processes and learning outcomes in ICT supported IBL students completed the survey [7] after participating in one of the teaching units. Descriptive analysis of collected data was conducted using SPSS version 21 (Statistical Package for the Social Sciences). Student percentage responses for two of the highest scores on a Likert scale (*a great deal* and *quite a bit* in the first section, *always* and *usually* in the second section of the survey) were summed and the means and standard deviations calculated.

RESULTS

Students' Perceptions of Learning Processes in ICT-supported IBL Teaching Units (Related to RQ1)

Figure 1 represents students' perceptions of learning processes in the teaching units.

The highest ranked types of learning were *understanding* (86.85%), *analysing* (85.28%), *applying* (84.10%) and *memorising* (83.78%) with regard to students' responses *a great deal* or *quite a bit*. The rest of students' responses ...*a great deal* or *quite a bit* related to *evaluating, creating* and *reflecting* and ranged from 67.55 % to 78.77 %.

The results are similar to findings of other researchers, who reported that students' perception of learning processes are rated well in various types of IBL courses [7].

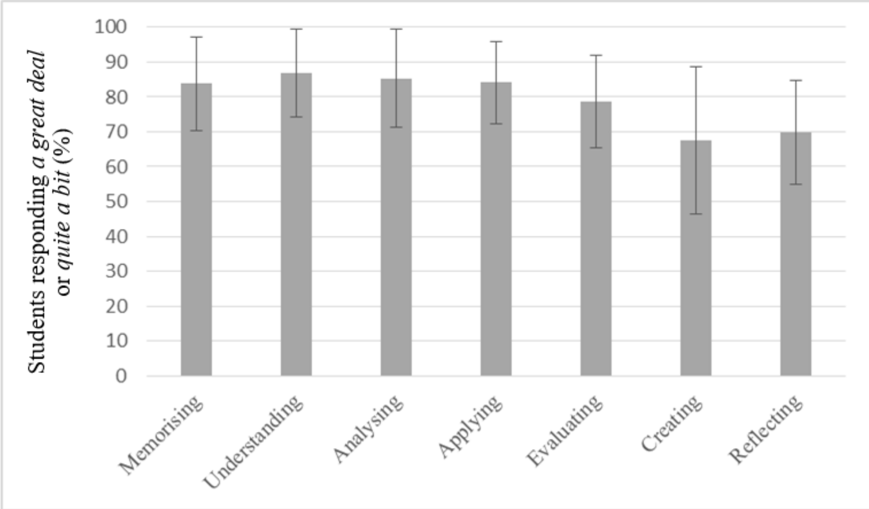

Figure 1: Mean scores and standard deviations for students' responsens in the first section of the survey.

Students' Perceptions of Learning Outcomes in ICT-supported IBL Teaching Units (Related to RQ2)

Figure 2 represents students' perceptions of learning outcomes in the teaching units. The IBL teaching units were the highest rated by students for *understanding, why were they studying, what they were studying* (92.05%) and for *learning how to solve problems and/or answer questions* (77.55%). More than two thirds of students rated the IBL teaching units highly for *being encouraged to take responsibility for their own learning* (70.87%) and for *learning more than they expected to by working with their peers* (69.55%) or *on their own* (68.17%).

Rating less highly were aspects including whether the IBL teaching units encouraged or allowed them to *think about how they are learning and not just what they were learning* (58.68%), to *make choices about what would they study* (55.88%), to *feel intellectually challenged by the IBL teaching unit* (55.23%), to *be faced with questions or problems with more than one possible answer* (54.78%) and to *discussed ideas or issues from the IBL teaching unit outside of class* (53.38%).

The lowest percentage of students responded that *always* or *usually* they *questioned their opinions, assumptions, and/or beliefs* during the IBL teaching unit (28.95%). Each of the students attended one of the seven ICT supported IBL teaching units that were developed and guided by future teachers as a part of their training.

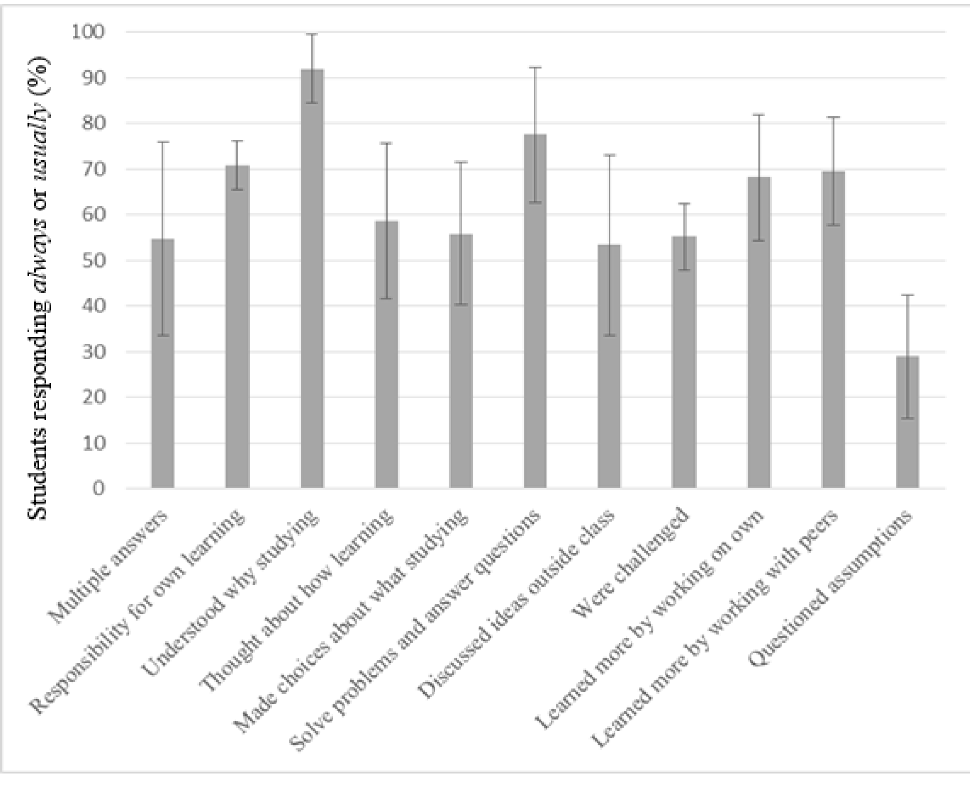

Figure 2: Mean scores and standard deviations for students' responses in the second section of the survey.

Similar to the findings of other researchers [7], in this study, there was recognition of both independent learning and learning from peers. The item related to questioning students' opinions, assumptions, and/or beliefs during the IBL teaching unit achieved the lowest percentage score.

CONCLUSIONS

The teacher's role in IBL is as a facilitator of the learning process in student-centred learning. ICT can play a vital role in searching, capturing, analysing and presenting the data. It is important to provide future STEM teachers with such experience in direct contact with students.

The research focused on a course in the second Bologna cycle, in which future STEM teachers, developed and implemented ICT supported IBL teaching units. The main aim of this study was to investigate students' perception of learning processes and intended learning outcomes in ICT supported IBL teaching units implemented by future STEM teachers.

The findings indicate that the majority of lower secondary school students, who attended the teaching units, perceived a *great deal* or *quite a bit* of positive effects on mental processes during IBL. Regarding students' perceptions of the intended learning processes, students had the greatest impression in *thinking about the purpose of experimental research*, learning *how to solve problems and/or answer questions* and encouragement *to take responsibility for their own learning*.

The results speak in favour of the described strategy for future teacher training related to the implementation of ICT supported IBL based on direct contact of future STEM teachers with students. Therefore, the authors are encouraged to proceed.

ACKNOWLEDGEMENTS

The authors would like to thank the financial support provided by the Republic of Slovenia and the European Union under the European Social Fund. In its framework, the project - ICT in Teacher Training Study Programmes of the University of Ljubljana - enabled the pilot-renewal of the herein described course. Any opinion, finding and conclusion or recommendation expressed in this material is that of the author and the European Commission does not accept any liability in this regard.

REFERENCES

1. Minner, D.D., Levy, A.J. and Century, J., Inquiry-based science instruction - what is it and does it matter? Results from a research synthesis years 1984 to 2002. *J. of Research in Science Teaching*, 47, **4**, 474-496 (2010).
2. Alfieri, L., Brooks, P.J., Aldrich, N.J. and Tenenbaum, H.R., Does discovery-based instruction enhance learning? *J. of Educational Psychology*, 103, **1**, 1-18 (2011).
3. Furtak, E.M., Seidel, T., Iverson, H. and Briggs, D.C., Experimental and quasi-experimental studies of inquiry-based science teaching: a meta-analysis. *Review of Educational Research*, 82, **3**, 300-329 (2012).
4. de Jong, T., Sotiriou, S. and Gillet, D., Innovations in STEM education: the Go-Lab federation of online labs. *Smart Learning Environments*, 1, **3**, 1-16 (2014).
5. Keselman, A., Supporting inquiry learning by promoting normative understanding of multivariable causality. *J. of Research in Science Teaching*, 40, **9**, 898-921 (2003).
6. Spronken-Smith, R. and Walker, R., Can inquiry-based learning strengthen the links between teaching and disciplinary research? *Studies in Higher Educ.*, 35, **6**, 723-740 (2010).
7. Spronken-Smith, R., Walker, R., Batchelor, J., O'Steen, B. and Angelo, T., Evaluating student perceptions of learning processes and intended learning outcomes under inquiry approaches. *Assessment & Evaluation in Higher Educ.*, 37, **1**, 57-72 (2012).
8. Staver, J.R. and Bay, M., Analysis of the project synthesis goal cluster orientation and inquiry emphasis of elementary science textbooks. *J. of Research in Science Teaching*, 24, **7**, 629-643 (1987).
9. White, B.Y. in Frederiksen, J. R., Inquiry, modeling, and metacognition: making science accessible to all students. *Cognition and instruction*, 16, **1**, 3-118 (1998).
10. Bybee, R.W., Taylor, J.A., Gardner, A., Van Scotter, P., Powell, J.C., Westbrook, A. and Landes, N., *The BSCS 5E Instructional Model: Origins and Effectiveness*. Colorado Springs: BSCS, 88-98 (2006).
11. Pedaste, M., Mäeots, M., Siiman, L.A., De Jong, T., Van Riesen, S.A., Kamp, E.T., Manoli, C.C., Zacharia, Z.C. and Tsourlidaki, E., Phases of inquiry-based learning: definitions and the inquiry cycle. *Educational Research Review*, 14, 47-61 (2015).
12. Dobber, M., Zwart, R., Tanis, M. and van Oers, B., Literature review: the role of the teacher in inquiry-based education. *Educational Research Review*, 22, 194-214 (2017).
13. Ben-David, A. and Zohar, A., Contribution of meta-strategic knowledge to scientific inquiry learning. *Inter. J. of Science Educ.*, 31, **12**, 1657-1682 (2009).
14. Jerzembek, G. and Murphy, S., A narrative review of problem-based learning with school-aged children: implementation and outcomes. *Educational Review*, 65, **2**, 206-218 (2013).

15. Avsec, S. and Kocijancic, S., Effectiveness of inquiry-based learning: how do middle school students learn to maximise the efficacy of a water turbine? *Inter. J. of Engng. Educ.*, 30, **6**, 1436-1449 (2014).
16. Avsec, S., Rihtarsic, D. and Kocijancic, S., The impact of robotics-enhanced approach on students' satisfaction in open learning environment. *Inter. J. of Engng. Educ.*, 32, **2**, 804-817 (2016).
17. Avsec, S. and Kocijancic, S., A path model of effective technology-intensive inquiry-based learning. *J. of Educational Technol. & Society*, 19, **1**, 308-320 (2016).
18. Šinigoj, V. and Avsec, S., Water and wind turbines optimisation using inquiry-based teaching: a Chain Reaction case study. *World Trans. on Engng. and Technol. Educ.*, 14, **1**, 64-69 (2016).
19. Gerard, L.F., Varma, K., Corliss, S.B. and Linn, M.C., Professional development for technology-enhanced inquiry science. *Review of Educational Research*, 81, **3**, 408-448 (2011).
20. Suárez, Á., Specht, M., Prinsen, F., Kalz, M. and Ternier, S., A review of the types of mobile activities in mobile inquiry-based learning. *Computers & Educ.*, 118, 38-55 (2018).
21. Zydney, J.M. and Warner, Z., Mobile apps for science learning: review of research. *Computers & Educ.*, 94, 1-17 (2016).
22. Sung, Y.T., Chang, K.E. and Liu, T.C., The effects of integrating mobile devices with teaching and learning on students' learning performance: a meta-analysis and research synthesis. *Computers & Educ.*, 94, 252-275 (2016).
23. Dobber, M., Zwart, R., Tanis, M. and van Oers, B., Literature review: the role of the teacher in inquiry-based education. *Educational Research Review*, 22, 194-214 (2017).
24. Schweisfurth, M., Learner-centred education in developing country contexts: from solution to problem? *Inter. J. of Educational Develop.*, 31, **5**, 425-432 (2011).
25. Volz, D.L. and Smola, R., *Investigating Chemistry through Inquiry*. (4th Edn), Beaverton: Vernier Software & Technology (2017).