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The Efficacy of Inquiry-based Learning in Undergraduate Physiology

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Abstract

Lecture, where learning is passive, remains a prevalent instructional method of teaching content. Contextualized approaches like Inquiry-Based Learning (IBL) where students are more actively engaged remains less common. For 25 years the literature has supported contextualized approaches. Nevertheless, recent papers have claimed IBL to be an unguided approach that has produced content knowledge deficits. Therefore, we tested whether undergraduate physiology content could be learned using IBL. Four groups of undergraduates (mean ages=23, N=60) took a ten-week physiology course using IBL. A content valid pretest and posttest measured content knowledge. A one-way ANOVA indicated no significant differences within or between groups on the pretest (F=.231) or between the groups on the posttest (F=.119). After collapsing the groups into pre and post, a paired T-test indicated a significant difference between pretest and posttest scores T (32)= -7.61, P>.0001. The data clearly demonstrated significant content knowledge gains and higher than average student satisfaction.

Introduction

Lectures remain a prominent method of instruction in many high schools and colleges where teachers and professors passively engage learners using oration and text rather than one of the newer contextualized learning approaches. One such contextualized approach called Inquiry-based learning (IBL) forces students to actively participate in their own learning while the teacher becomes more of a facilitator of learning. _Inquiry-based learning facilitates higher levels of student engagement, critical thinking skills, and knowledge retention. The Association of American Colleges and Universities states that the goal of education is to "provide multiple opportunities for students to engage in 'inquiry-based learning,' both independently and in collaborative teams…to learn how to find and evaluate evidence, how to consider and assess competing interpretations, and assess competing interpretations" (Fitzpatrick & Campisi 2009, p. 354).

Also referred to as problem-based learning (PBL), IBL has been touted as a viable alternative to conventional teaching approaches and has been used in a variety of disciplines (Savery & Duffy, 1995) and educational levels (Savery, 2006). Numerous Institutions of Higher Education, such as McMaster University and Loyola University Maryland, include IBL courses in their curriculums. McMaster has used IBL in its curriculums for more than three decades and other universities are beginning to follow their lead. The contextualized approach of IBL and PBL in particular have become increasingly common at the university level in the past decade, growing from 10% to approximately 80% in university science classrooms (Sundberg, Armstrong, & Wischusen, 2005). Despite this growth, critics question whether IBL can provide students with sufficient content knowledge gains.

Inquiry-based learning flips the responsibility of active engagement from teacher to student. It is defined as "focused, experiential learning organized around the investigation, explanation, and resolution of meaningful problems" (Barrows, 2000; Torp & Sage, 2002) and uses realistic problems such as medical diagnosis or lesson design (Barrows, 2000; Hmelo-Silver, 2004) to fully engage students in active learning and research.

Using a meta-analytic method, Dochy, Segers, Van den Bossche, and Gijbels (2003) reviewed 43 empirical studies on PBL in post-secondary education. The authors found that PBL yielded a substantial positive effect on the skills of students (p. 533). None of the 43 studies showed a negative effect, and there was a moderate effect size on knowledge application that favored PBL students. Brickman, Gormally, Armstrong, and Hallar (2009) also found an increase in content knowledge. Students in IBL laboratories had a content knowledge increase of 4% between pre- and posttests, while students in traditional classrooms showed no significant difference between pre- and posttests. Additionally, Mergendoller, Maxwell, and Bellisimo (2006) found that across multiple teachers and schools, students who were in PBL courses gained more knowledge than students who were in traditional courses.

Inquiry-based learning has also been associated with higher levels of student engagement. Healey and Jenkins (2000), Healey (2005) and Justice, Rice, Roy, Hudspith, and Jenkins (2009) found that the inquiry-based approach increased student engagement in coursework. Kolkhorst, Mason, DiPasquale, Patterson, and Buono (2001) found that students enrolled in inquiry-based coursework were highly engaged and enthusiastic, and post-course journal entries, surveys, and interviews indicated that the students had a sense of empowerment and ownership in their work. Graduate assistants also reported a greater comprehension of the scientific process.

Casotti, Rieser-Danner, and Knabb (2008) noted that inquiry-based physiology laboratories "improve students' critical- and analytical-thinking skills" (p. 286). The authors implemented an IBL approach with three courses: Comparative Vertebrate Physiology (majors), Human Physiology (majors), and Human Anatomy and Physiology (nonmajors). The authors found that an inquiry-based curriculum enhanced the students' comprehension of the scientific approach and of physiological concepts.

Despite the evidence supporting the efficacy of IBL and PBL, Justice et al. (2009) state that there are "extra-pedagogical challenges [with] introducing and maintaining inquiry-based learning in the curriculum" (p. 841) and that the introduction of new pedagogies are often met with resistance at the university level. Contextual learning is not a new pedagogy; it has deep roots in education. John Dewey introduced experiential learning at the turn of the 20th century and therefore contextualized learning approaches have had a long history in the literature but less of a history of implementation in the elementary, secondary, and post-secondary classrooms.

Fitzpatrick and Campisi (2009) describe a project with two groups of students, one in a physiology course and one in a statistics course, who collaborated in physiological data analysis. The IBL approach "aided student recognition of statistics in data analysis…and the use of meaningful real-world open-ended data with no known answer…[was] a major contributor to positive outcomes of the project goals" (p. 354).

Rivers (2002) also developed an inquiry-based laboratory that presented students with an alternative approach for learning physiology. Rivers found that the students who completed this IBL model at Loyola University Maryland exhibited high levels of educational commitment as well as proficiency in the biological sciences. Rivers concluded that students "need the opportunity to be engaged and active in their learning: to do science rather than just learn about science" (p. 317). The author aimed to implement IBL throughout the biology curriculum, with

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techniques and topics selected specifically for student engagement. Students worked in groups of 3-4 to develop hypotheses and design experiments based upon their readings of primary research. The student teams developed mini-proposals for each topic and brainstormed with the instructor when alternative approaches were advisable. Student-directed brainstorming sessions using roundtable discussions were expected to generated student-driven solutions.

Elton (2001) found that student-centered teaching and learning processes lead to a "positive nexus for the most able students" (p. 43). Healey (2005) concurred, finding that "appropriately designed student-centered approaches [fostered] deep learning" (p. 7). An increased emphasis on active student engagement would also enhance the research and teaching connection.

Gilardi and Lozza (2009) examined a course entitled "Practical Experience of Internship", which sought to promote students' planning with a particular context. Groups of 8-10 students were paired with real companies where they executed field research projects that related to problems in marketing or organization. Students in this course indicated that they sufficiently mastered the abilities in their assessment questionnaire. The highest ratings, with means above 5.5 out of 7, were for teamwork, reporting, research/intervention design, and self-reflection. Gilardi and Lozza (2009) state that inquiry-based education promotes professionalism and field research practice "encourages a revision of tacit epistemological beliefs among students" (p. 253).

Not every educator believes in the efficacies of contextual learning approaches. Kirschner, Sweller, and Clark (2006) argue that unguided instruction is less effective [than guided instruction], indicating that there is a potential negative effect on student learning when students acquire misconceptions or incomplete information. The authors base this conclusion on the premise that "[minimally guided instructional approaches] ignore the structures that constitute human cognitive architecture and evidence from empirical studies… consistently indicate that minimally guided instruction is less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process" (p. 75). The authors note that the minimally guided approach has been called by various names, including "'discovery learning,' 'problem-based learning,' 'inquiry-learning,' 'experiential learning,' and 'constructivist learning'" (p. 75) but do not discern any differences between these titles.

In a rebuttal to Kirschner et al. (2006), Hmelo-Silver, Duncan, and Chinn (2007) state that the aforementioned authors grouped together disparate approaches, namely, problem-based learning and inquiry-based learning with discovery learning. Hmelo-Silver et al. (2007) note that the "problem with [Kirchner et al.'s] line of argument is that…[they] have mistakenly conflated PBL and IBL with discovery learning" (p. 99). The authors note that Kirschner et al.'s (2006) work has two major flaws: namely, a pedagogical one and an evidentiary one. With the pedagogical error, Kirschner et al. "indiscriminately lumped together several distinct pedagogical approaches: constructivist, discovery, problem-based, experiential, and inquiry-based learning under the category of guided instruction" (Hmelo-Silver et al., 2007, p. 99). The evidentiary flaw relates to their claim that PBL and IBL are ineffective instructional approaches and is "contrary to empirical evidence that…supports the efficacy of PBL and IBL as instructional approaches" (Hmelo-Silver et al., 2007, p. 99). In IBL, students engage in self-inquiry, learning content, strategies, and self-directed learning skills through collaborative efforts. Through this collaborative engagement, students learn content and discipline-specific reasoning skills and practices (Hmelo-Silver et al., 2007). In both PBL and IBL, the teacher is the guiding facilitator to student learning and the approaches are not minimally guided because of numerous forms of scaffolding, including scaffolding that "makes disciplinary thinking and strategies explicit" (p. 100), "embeds expert guidance" (p. 101), and "structures complex tasks or reduces cognitive loads" (p. 102).

Students in IBL and PBL classes generate more effective solutions to problems and yield higher gains in posttest scores. Hmelo (1998) noted that a longitudinal quasi-experimental study of first-year medical students found that "PBL students generated more accurate and coherent problem solutions than traditional medical students" (p. 103). Similar results were found for preservice teachers in a PBL course in educational psychology. Over the course of three semesters, there were "consistently positive effects favoring the students in the PBL class on targeted outcomes" and on "measures of declarative knowledge, there were no differences…[but] students constructed more integrative explanatory essays for concepts that they had learned using a PBL approach" (p. 103). Kirschner et al. (2006) assert that there is a lack of research using controlled experimentation exhibiting the effectiveness of PBL and IBL methods. Hickey et al. (1999), however, found that 381 students in a PBL course showed significantly larger gains from pretest to posttest than the 107 students who were in [non-PBL] classrooms (p. 104).

With IBL, the focus is on acquiring knowledge and reasoning strategies. Brickman et al. (2009) note that IBL is being promoted to increase skill development among science students. Numerous studies (Brickman et al., 2009; Casotti et al., 2008; Dochy et al., 2003; Mergendoller et al., 2006) find significant content knowledge gains in comparison to traditional curriculums and IBL appears to be a promising teaching method in terms of level of student engagement, increases in student knowledge, and increases in student outcomes as measured by pre- and posttest scores. Given the disparity between fields of thought, a first introduction to IBL with undergraduates might yield the most profound results.

Purpose

While there is a growing body of literature that supports IBL as a robust method, other papers question its unguided effectiveness in making sufficient gains in content knowledge. Despite the evidence supporting the efficacy of IBL and PBL and support for increasing IBL in science curriculums (Brickman et al., 2009) Justice et al. (2009) assert that IBL has "extra-pedagogical challenges…with introducing and maintaining [it] in the curriculum" (p. 841). Kirschner, Sweller, and Clark (2006) argue that unguided instruction is less effective than guided instruction, asserting that it can potentially cause students to acquire misconceptions and incomplete information. Conversely, Hmelo-Silver et al. (2007) argue that in IBL, students "learn content, strategies, and self-directed learning skills through collaboratively solving problems, reflecting on their experiences, and engaging in self-directed inquiry" (p. 100). In IBL, students "learn content as well as discipline-specific reasoning skills and practices…by collaboratively engaging in investigations" (p. 100).

Using federal grant funds from 2001-2004, we demonstrated four distinctively effective IBL approaches using four high schools. A monograph describing this work (DePaepe, 2005) is available at this website - cwu.edu/~ectl/ore/research.html. As a result, a few university science professors began using the IBL approach in content classes. Nevertheless, campus critics voiced opposition using the commonly used cliché claiming that there would be probable deficits in content knowledge. Therefore, this investigation was designed to test whether or not students receiving ten weeks of IBL instruction in an undergraduate physiology class could achieve

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sufficient content knowledge as measured by pretest posttest gains. We hypothesized that significant gains could be made. We also hypothesized that student satisfaction scores would not be as high as the university average, because students had not heretofore experienced inquiry-based or problem-based learning approaches, and would be more comfortable learning in a traditional classroom. The study received IRB approval.

Methods

Four groups (N=60) of undergraduate physiology students (mean ages=23) participated in a ten-week IBL course, "Health and Physiological Fitness Concepts for Teachers." The purpose of the course was threefold: 1) To achieve a greater proficiency in searching, reading, deciphering, and evaluating physiology literature that is credible and appropriate for school-aged children; 2) To learn basic physiology principles directly associated with health and fitness for school-aged children; and 3) To demonstrate competence in writing about and teaching basic physiology at a level appropriate for specific age groups. Diversity was low, with 8% Hispanic, 1% Asian, 1% African American, and 90% Caucasian. The IBL course was designed around 19 physiological problems and 36 sub-problems, which the students were required to research, discuss, and arrive to an agreed conclusion. All groups were pretested and posttested using the same content valid instrument. The test questions were partly adapted from the online test in *Applied Exercise & Sport Physiology* text by Housh, Housh and Deveries (2006). For Example: anaerobic metabolism is the production of ATP without Oxygen (true or false); an isocaloric state is achieved when calorie intake is equal to caloric expenditure (true or false); and high intensity workouts are shown to be less effective in improving cardiovascular fitness and reducing fat mass when compared to moderate intensity workouts (true or false).

Three groups were pretested and all four groups were posttested. Groups one (n=13), two (n=18), and three (n=15) were pretested and posttested. To ensure that students did not study for the test and used a true IBL approach, groups one and two were unaware of the posttest. Group three (n=15) was informed of the posttest and had an opportunity to prepare. To examine pretest sensitivity, group four (n=14) did not receive a pretest and had no knowledge of the posttest. While the pretest/posttest design improves internal validity, external validity is sacrificed. Thus, group four provided an accurate gauge of whether the study had both internal and external validity. A graduate assistant examined all of the class results after the course posttests were returned as a means to avoid bias.

Results

A one-way ANOVA determined there were no significant differences between groups on the pretest (F=.231) or posttest (F=.119). Pretest sensitivity tested negative. Even when group three students were made aware of the posttest and had an opportunity to study, there was no significant difference between their posttest scores and the other groups' posttest scores. Groups (1-3) were combined into two groups and paired (pre and post). A paired T-test indicated a significant difference between pretest and posttest T (32)= -7.61, P>.0001. All groups also completed an evaluation of instruction. Results of that measure indicated an above university average score on student satisfaction.

Students also gave the course very high ratings in anonymous post-course Student Evaluations of Instruction (SEOIs). The mean score for the confidence in the instructor's knowledge was 5.00 out of 5.00, compared to an overall university mean score of 4.65. The mean score for meeting the course objectives was 4.93 out of 5.00, compared to an overall university mean of 4.60. The mean score for evaluative and grading techniques was 5.00 out of 5.00, compared to an overall university mean of 4.43. The mean score for the instructor's teaching effectiveness was 4.80 out of 5.00 compared to an overall university mean of 4.34. The course as a whole was rated a 5.00 out of 5.00 compared to an overall university mean of 4.26. All students rated the course "excellent" overall. Written student comments on the SEOI were also unanimously positive, complimenting the course, the instructor, and the level of engagement offered by IBL.

Conclusion

Similar to Rivers (2002), this inquiry-based class provided an invigorating approach for exploring the principles of physiology. Similar to Brickman et al., 2009; Casotti et al., 2008; Dochy et al., 2003; Gilardi and Lozza 2009; and Mergendoller et al., 2006, the students in the current study significantly gained content knowledge. Similar to Healey and Jenkins, 2000; Healey, 2005; Justice et al., 2009, the student engagement level was also high. The culmination of the course involved the creation of end-of-quarter lessons that each student researched and taught their classmates. Internal and external validity were confirmed with a research design that included groups with pre- and posttests, informed posttests, uninformed posttests, and a posttest only.

The undergraduate students in this course had not been introduced to the IBL approach before. The course was an effective demonstration of inquiry-based learning. Most students felt empowered to be unguided in their own learning. While the debate over the efficacy of IBL endures, the evidence for the success of IBL continues to accumulate. Given the statistically significant differences from pretest to posttest content knowledge, high course evaluation scores, and positive comments on the SEOIs, the course appeared to be successful for the teacher, for the students, and for the future of inquiry-based learning in university pedagogy.

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