THE INTERDISCIPLINARY JOURNAL OF PROBLEM-BASED LEARNING

Design and Implementation of a Problem-Based Learning Module in a Clinical Radiography Course to Foster Image Critique Skills: An Evaluative Case Study

Vesna Balac (Indiana University Northwest)
Gamze Ozogul (Indiana University)

IJPBL is Published in Open Access Format through the Generous Support of the School of Education at Indiana University, the Jeannine Rainbolt College of Education at the University of Oklahoma, and the Center for Research on Learning and Technology at Indiana University.

The Interdisciplinary Journal of Problem-based Learning

2023 SUMMER ISSUE

Design and Implementation of a Problem-Based Learning Module in a Clinical Radiography Course to Foster Image Critique Skills: An Evaluative Case Study

Vesna Balac (Indiana University Northwest) & Gamze Ozogul (Indiana University)

ABSTRACT

Numerous studies have been conducted to examine the effectiveness of problem-based learning (PBL) in higher education programs, such as undergraduate nursing programs. Even though undergraduate nursing education and radiography education have similarities, studies that focus on the effectiveness of PBL in radiography have not been documented in literature. While the nature of the nursing and radiography disciplines may lead radiography educators to believe that PBL use in radiography education may be appropriate, based on existing research in nursing, its effectiveness and student attitudes need to be researched before curriculum-wide PBL implementation is planned. A mixed methods evaluative case study was conducted to investigate if a PBL module had an effect on radiography students' image critique skills and their perceptions. Quantitative data collection instruments consisted of a pretest and a posttest to assess students' image critique skills before and after PBL. Qualitative data collection instruments included a pre- and post-PBL survey, as well as structured reflections after the PBL module. The results showed a statistically significant difference between the pretest and the posttest, suggesting that the PBL module improved image critique skills in radiography students. In addition, students reported to feel significantly better prepared for image critique after PBL, and perceived working in a group as a good way to practice critiquing images. Difficulties reported were related to working in a group and transitioning to PBL, most likely due to being accustomed to lecture-based instruction.

Keywords: problem-based learning, radiography, image critique skills, student outcomes, instructional design

Numerous studies have been conducted to examine the effectiveness of problem-based learning (PBL) in higher education programs that prepare health professionals for their clinical careers (Albanese & Dast, 2014; Álvarez-Cruces et al., 2020; Jin & Bridges, 2016). Even though the very first implementation of PBL was designed for small-group learning in medical education, PBL has been used and studied in larger undergraduate nursing programs (Arrue et al., 2017; Baker, 2000; Beers, 2005; Carvalho et al., 2017; Choi et al., 2014; Gholami et al., 2016; Rideout et al., 2002; Smith & Coleman, 2008; Tiwari et al., 2006). While undergraduate nursing and radiography education have similarities, such as program structure that includes both didactic and clinical education components, and the requirement that both programs prepare students to take certification examinations required for employment (ASRT, 2022; National Council on State Board of Nursing, 2017), the use of PBL in the radiography education has not been documented in literature until recently. An EBSCO host search conducted in October 2022 that focused on the use of PBL in radiography within the last ten years resulted in only three articles (Kowalczyk, 2012; Mpalanyi et al., 2020; Takayoshi et al., 2016). However, none of these articles describe original research that focuses on effectiveness of PBL in radiography. Instead, they focus on students'

and/or educators' perceptions related to PBL (Mpalanyi et al., 2020; Takayoshi et al., 2016) or the role of the educator in the PBL process (Kowalczyk, 2012).

PBL is an "instructional method in which students learn through facilitated problem solving" (Hmelo-Silver, 2004, p. 235). PBL typically involves a small group of self-directed learners who develop content knowledge, critical thinking strategies, and collaborative learning skills through a facilitated experience of solving meaningful, authentic problems (Ertmer & Glazewski, 2019; Hmelo-Silver, 2004). The purpose of PBL is not only to develop self-directed learning skills, but also to instill the responsibility for lifelong learning and continued professional growth (Barrows, 1994). Albanese and Mitchell (1993) described PBL as "an instructional method characterized by the use of patient problems as a context for students to learn problem-solving skills and acquire knowledge about the basic and clinical sciences" (p.53). Furthermore, PBL can be described as experiential learning during which knowledge is actively constructed (Hmelo-Silver, 2004).

Problem Statement

Radiographers are mainly responsible for capturing diagnostic images of patients' anatomical structures using x-ray equipment (ASRT, 2022). The production of a diagnostic image involves an exponential number of image critique variables, including patient anatomy, pathology, radiographic positioning, and radiation protection, to name a few. Therefore, there are numerous variables that can affect the quality of a radiographic image, as well as the possibility of these factors acting upon each other, resulting in an astronomical number of possible imaging problems. This complexity makes image critique a moderately structured problem (Carlton et al., 2020), making it suitable for PBL pedagogy. When a radiographic image is outside of acceptance limit, multiple solution paths usually exist, leading to a high number of corrective actions and making the problem-solving process more challenging, which makes mastering radiography image critique difficult (Carlton et al., 2020). The skill to critique radiographic images is acquired with clinical experience and requires extensive knowledge of image critique variables, making it difficult to teach directly. Because it is expected that radiographers enter the workforce with mastery of image critique, it is essential that they practice this problem-solving process using realistic scenarios, while combining knowledge acquired both in clinical and didactic coursework. Thus PBL could be an appropriate instructional method for teaching and mastering this skill. However, the design of PBL and effectiveness of this method has to be studied before it is adopted in the radiography curriculum.

Research Questions

Given the very limited research of PBL use in radiography education, and the continued demand from healthcare employers for radiography program alumni to be fully prepared to critique images upon graduation, this study aims to answer the following research questions:

1. How does PBL affect image critique skills of the second-year radiography students?
2. What are students' perceptions regarding the use of PBL when learning how to critique radiographic images?

Methods

This research utilized a mixed methods evaluative case study (Yin, 2014). A mixed methods approach affords the researcher the opportunity to utilize strengths of both qualitative and quantitative methods (Fraenkel et al., 2011), and to collect direct and self-report data to be cautious of self-presentation bias (Kopcha & Sullivan, 2007). Due to the complexity of the PBL phenomenon and its under-researched use in radiography education, mixed methods were warranted as the combined advantages of qualitative and quantitative methods could provide stronger evidence for a conclusion (Fraenkel et al., 2011). Moreover, an evaluative case study design was selected because this method is recommended when a phenomenon needs to be studied in a real-life context and when the "how" or "why" research questions concerning that phenomenon are being addressed (Yin, 2014).

Participants and Context

This study was conducted with 33 second-year students registered in the radiography program at a regional campus of a large midwestern public university system located in an urban setting. The radiography program is offered as a full-time program, and has classroom and laboratory components that take place on campus, and clinical experiences at local hospitals. Every June, the program admits about 36 students, who progress through their studies as a cohort. The group that participated in this study included 31 females and two males, with an average age of 26.3.

PBL Module Design and Course Materials

To answer the two research questions, a six week-long PBL module described below was designed and delivered. The PBL module did not focus on any specific content area, but instead it aimed to help students further develop their radiography image critique skills.

Introduction to the PBL Process

The majority of the students were new to PBL, due to being accustomed to more traditional instructional methods used in the specific radiography program. Therefore, the students needed to be introduced to PBL (Woods, 1996) and learn about the change in classroom dynamics associated with this method that is due to a shift of activity from the instructor to the student. To introduce the PBL process, the researcher recorded a screencast to explain the overview of PBL, introduce student and facilitator roles, explain what is expected of students on a conceptual level, and outline some of the details related to group work, learning activities, and assessments. The screencast was shared with students online, during the first week of the module, using the learning management platform.

Learning Activities

The learning activities were designed relying on the Socio-Technical Environment for Learning and Learning-Activity Research (STELLAR) course development system and eStep activities. STELLAR was designed to help college students develop:

> 1) meshed cognitive representations (representations bringing together course concepts with perceptual visions of practice and plans for practice), which should support spontaneous transfer of course knowledge to professional practice; and 2) mindsets for collaboration, self-directed learning, and reflective practice in tool-rich environments, which may help support life-long professional growth. (Derry et al., 2006, p. 146-147)

To accomplish the first STELLAR goal of developing meshed cognitive representations, learning activities described in Steps 2 through 4 were developed, as outlined in Figure 1. Figure 1 also presents the progression of the PBL module from week to week. A real-life problem scenario, which included a radiographic image of poor quality (see Figure 2) that was obtained in real clinical practice, was developed to guide this learning experience and initiate student engagement, and was introduced in Step 2. Simply introducing the problem does not initiate student inquiry, which is one of the difficulties that students tend to experience (Ertmer & Glazewski, 2015). To help mitigate this issue and initiate student buy-in, the scenario was presented using a video that showed a radiographer who finished a trauma hip procedure for her colleague, but did not perform the examination, and therefore, did not know what led to the errors on the resulting image, leaving it up to the students to act as that radiographer and solve the problem related to improving the image for the repeated examination. The driving question "How do I critique an image with multiple errors and identify corrective actions to improve image quality?" was used to guide the PBL process, and it also points to the complexity of image critique. Furthermore, to elevate the purpose, the facilitator presented primary resources related to medical malpractice in radiography that resulted from poor image quality to increase student engagement and motivation. Additionally, graphic organizers and deadlines were provided in Step 3, as recommended in the literature (Ertmer & Glazewski, 2015). To initiate collaboration, establishing student roles and ground rules was also planned for this step.

The second STELLAR goal was to help students develop skills related to self-directed learning, collaboration, professional development, and reflective practice. The initiation of this self-directed process was planned for Step 4, during which students identified learning gaps. During Step 5, students defined the task and generated hypotheses, using a worksheet established to record information relevant to the problem, consider initial ideas and learning issues, develop an action plan (Hmelo-Silver & Ferrari, 1997), and set learning objectives. Hard scaffolds were prepared in advance to facilitate the continuation of the group process. In Step 6, students conducted research using library databases, to gather information necessary for problem-solving, as well as to become familiar with professional journals, and set in motion a desire for lifelong learning and professional development, supporting the second STELLAR goal. To promote mindset for collaboration, Steps 5, 7, and 8 were developed, to help students create a group response to the problem and prepare their final presentations, supporting both STELLAR goals. The scoring rubric, as well as other hard scaffolds selected to help students prepare a response that meets the grading criteria, were also included. Step 9 included the delivery of student presentations, as well as the opportunity for the facilitator and other clinical faculty to assess content learning and presentation delivery skills. A debriefing exercise was also planned to allow clinical faculty and the facilitator to share their feedback, and provide student groups with the opportunity to reflect on their accomplishments. Reflective self-feedback practice consistent with the second STELLAR goal was assigned in Step 10, as well as during self-assessment completed in Step 11.

Facilitation Techniques

Facilitation techniques for the PBL included forming groups, strategies for anticipated difficulties, and scaffolding.

Groups were formed using the clinical schedule utilized to divide students for the purpose of placement at the local hospitals, where students complete their clinical education,

	Description	Assessment	Participation	Timeline
Step 1	View screencast focusing on PBL definition and background, change in classroom dynamics, student and facilitator roles, and what students can expect from this module.	Reflection	Group, face-to-face	Week 1 (meet for two hours)
Step 2	Review Learning Activities- each group establishes ground rules and selects roles for individual members.	Verbal Report	Group, face-to-face	Week 1
Step 3	Review radiographic image and the scenario, and record their observations.	Reflection; Verbal Report	Group, face-to-face	Week 1
Step 4	Complete KWH part of the chart using a whiteboard.	Verbal Report	Group, face-to-face	Week 1
Step 5	Complete the FILIAP worksheet to establish a potential hypothesis, an action plan, and distribution of workload; set learning objectives using hard scaffolds.	Verbal report	Group, face-to-face	Week 2 (meet for 2 hours)
Step 6	Conduct additional research through university library databases individually; other actions defined in step 5 also completed.	Peer- and self-Assessment; Verbal report	Individual	Week 2
Step 7	Share and discuss results of their individual research, revise initial hypothesis, as needed, and formulate solution to the problem.	Verbal report	Group, face-to face	Week 3 (meet for 2 hours)
Step 8	Create a PowerPoint presentation with a problem solution and corresponding evidence, and prepare for the delivery of their presentation.	Verbal report	Group, face-to-face	Week 4 (meet for 2 hours)
Step 9	Deliver group presentations; Group discussion and debriefing occur once all presentations are delivered.	Group presentation grading rubric	Group, face-to-face	Week 5 (meet for 2 hours)
Step 10	Reflect on the PBL module by completing the structured reflection assignment.	Structured Reflection Assignment	Individual	Week 6
Step 11	Complete peer- and self- assessment.	Peer-assessment	Individual	Week 6

Figure 1. Description of the learning activities

Note. Adapted from Cognitive transfer revisited: Can we exploit new media to solve old problems on a large scale?, by S. J. Derry, C. E. Hmelo-Silver, A. Nagarajan, E. Chernobilsky, & B. D. Beitzel, Journal of Educational Computing Research, 35(2), 145-162.

Figure 2. Radiographic image of poor quality used to guide student learning in the PBL module

which allowed students to stay with the peers they already worked with. The clinical schedule divided 33 students into nine groups consisting of two to five students. To make the group sizes similar for this study, groups that consisted of two and three students were combined, resulting in seven groups of four to five students. At their first face-to-face meeting, students established ground rules, as well as assigned the following group member roles:

- Timekeeper—ensures group stays on track
- Summarizer—provides a summary of the discussion for other students to approve or amend, and delivers verbal reports at the end of each group discussion
- Recorder—takes notes on the whiteboard
- Team member(s)—participates in discussion and reviews resource materials

Difficulties related to implementing PBL that have been identified in the literature (Belland et al., 2013; Ertmer & Simons, 2006; Ertmer & Glazewski, 2015) were anticipated in this research. First, active student engagement (Belland et al., 2013) was considered, as well as sustained participation through the life of the problem, which becomes an issue when students do not use their group time productively. To mitigate this difficulty, frequent check-ins have been recommended (Ertmer & Simons, 2005; Ertmer & Glazewski, 2015). Consistent with this recommendation, students were asked to deliver verbal group reports at the conclusion of each discussion, to outline groups' accomplishments. Second, accountability and fair workload distribution have been identified as a potential issue, especially in large classes (Woods, 1996). Peer- and self-assessments were designed to help minimize these problems (Woods,1996) and improve learning outcomes through peer- and self-feedback (Ozogul & Sullivan, 2009). Finally, to mitigate difficulties related to adjusting to student-centered learning environment (Asghar et al., 2012; Goodnough & Cashion, 2006), sufficient scaffolding had to be provided (Ertmer & Glazewski, 2019) to support the transformation of responsibility.

Scaffolds are used in PBL to help initiate student inquiry, promote concept integration, resolve misconceptions, and promote reflective thinking (Ertmer & Simons, 2005). Scaffolds that are anticipated in advance, during the planning stages of PBL, are known as hard scaffolds. Following hard scaffolds were prepared for this PBL module, to support specific areas:

1. Pertinent textbook chapters—shared in Step 5 (supports development of meshed-cognitive representations and content knowledge)
2. The procedure guide for library databases—shared in Step 6 (supports professional development and self-directed learning)
3. Peer/Self-Assessment Instrument—shared in Step 3 (supports development of collaboration skills and outlines what is expected of students)
4. Grading rubric—shared in Step 8 (supports creating final group presentations).

Soft scaffolds are those that cannot be anticipated and can be delivered as just-in-time instruction. Some examples include providing new information based on students' needs or requests, as well as asking questions to clarify or verify student understanding (Ertmer & Glazewski, 2019). Therefore, the need for soft scaffolds could not be planned, but was identified during student discussions, through close monitoring of the PBL process. The researcher/facilitator planned to continually rotate among groups, to monitor their discussion, and serve as a metacognitive coach who guides the development of higher order thinking skills, through metacognitive questions and modeling.

The researcher/facilitator planned to use questioning techniques that push students for explanations during group discussions. These techniques involved "how" and "why" questions to stimulate synthesis, analysis, and evaluation of information that students bring up during the discussion, particularly in Steps 4 through 7. The goal of questioning techniques was to help develop students' clinical reasoning, while steering their focus away from lower cognitive level domain. To challenge students to apply what they already know, the researcher/facilitator planned to utilize revoicing and summarizing, especially as students generate hypotheses. As the researcher/facilitator steps into the role of a metacognitive coach, she planned to utilize metacognitive

questions, which are "domain general and refer to planning, monitoring, controlling, and evaluating the problem-solving process" (Hmelo-Silver & Ferrari, 1997, p.412), rather than cognitive questions, which "address domain-specific knowledge and procedures needed to solve the problem" (Hmelo-Silver & Ferrari, 1997, p.412). To help accomplish this, the following strategies were planned:

- Jump starting—asking students about how they will approach the problem
- Check-ups—asking students to think about how what they are discussing relates to their goal of solving the problem
- Stepping back—asking students to step back and talk about their goals, which assures that they remain focused on the problem
- Dropping hints—helping students move forward when they are stuck in the problem-solving process (Hmelo-Silver & Ferrari, 1996).

Fidelity of Implementation

Fidelity of implementation refers to the extent to which what is planned is delivered as intended, and as such, affects the credibility of research. Therefore, to assure credibility, in addition to providing the implementation plan, researchers need to document whether the intervention had actually been implemented as planned (Carroll et al., 2007). To accomplish this, a researcher/facilitator diary form was developed and completed at the beginning and conclusion of every session, to outline the plan for each session, provide an opportunity for post-implementation summary/reflection, as well as detail any adaptations.

Assessment

Summative assessment in the context of PBL can be designed as individual assessments, such as peer- and self-assessments (Klegeris & Hurren, 2011; Papinczak et al., 2007; Savin-Baden, 2004), while group presentations and projects are suggested for assessing group work (Kelly & Finlayson, 2007; Reynolds & Kearns, 2017; Savin-Baden, 2004). Additionally, the use of formative assessment is recommended to support learning and may include "minute papers (Angelo & Cross 1993) and verbal reports of group discussions" (Reynolds & Kearns, 2017, p. 19). Based on these recommendations, student learning in this PBL module was assessed using verbal reports, group presentations, pre- and post-test, as well as peer- and self-assessment.

Group verbal reports were used to assess the second STELLAR goal, which is to help students develop skills related to self-directed learning, collaboration, professional development, and reflective practice. This assessment was also used formatively to support learning, discover misconceptions, provide feedback, and help students establish a shared understanding, maintain their agenda, and accomplish their learning objectives through metacognitive coaching.

Group oral presentations were used to assess evidence of content learning indicated in the first goal of developing meshed cognitive representations. While the development of oral communication skills is not one of the STELLAR goals, this criterion was assessed due to its importance in the radiography curriculum.

Students assessed their own learning process and that of their peers using peer- and self- assessment. The instrument was adapted from Papinczak et al. (2007) to help hold students more accountable, as well as to measure the development of skills related to self-directed learning, collaboration, and reflective practice, which are outlined in the second STELLAR goal. This instrument was validated and found to have high values for Cronbach's alpha (0.76 to 0.84), indicating strong internal consistency, as well as Pearson correlation coefficients of 0.40 to 0.60 (Papinczak et al., 2007) implying acceptable reliability. Each student completed the instrument for all group members, including themselves, rating 16 categories, ranging from 1 (strongly disagree) to 5 (strongly agree).

Data Collection Instruments and Procedure

Pretest-Posttest

The pretest-posttest instrument (see Figure 3) was designed to assess the improvement of image critique skills. Similar to the assessment instrument used in the STELLAR system utilized by Derry et al. (2006), the pretest-posttest instrument consisted of open-ended questions. Pretest was administered one week prior to implementation of PBL to assess the existing image critique skills. The same instrument was administered as the posttest, after the students completed the PBL module and delivered final presentations, which was six weeks after the pretest, to mitigate the improvement due to the test/retest effect. Furthermore, no feedback was provided for the pretest, to assure that students did not learn from the questions asked on the pretest. The instrument was pilot tested by ten subject matter experts from the researcher's institution to ensure its validity. Since the pretest-posttest instrument included problems with multiple correct answers, a scoring guide was established by compiling all possible correct answers identified by ten subject matter experts, and the maximum score of 32 points for the tests was established. The instrument included one image of an axiolateral projection of the hip, to help assess image critique skills specific to this projection, which was also used in the PBL module. The maximum score possible for this question was six points.

As open-ended questions were used for the pretest-posttest instrument, interrater reliability procedures were used to establish the scoring guide, which was used to score the pretest and the posttest responses. After the pretest-posttest instrument was finalized and administered to the students, another subject matter expert, unaware of the pretest or posttest implementation rounds, scored all of the tests, and calibrated with the researcher. Inter-rater agreement was 90.63% for the pretest and 93.75% for the posttest, while 100% agreement was reached for the hip image pretest question and 93.75% for the hip posttest question.

Surveys

Two surveys were administered online, before and after the PBL module. The pre-PBL survey (see Appendix A) comprised six Likert scale items with five points ranging from 1 (strongly disagree) to 5 (strongly agree), followed by two open-ended items concerning students' perceptions related to group learning. Internal reliability of the pre-PBL survey, using Cronbach's alpha, was 0.57. The purpose of this instrument was to capture students' perceptions related to their preparedness to critique radiographic images, as well as their perceptions related to working in collaboration with their peers, prior to PBL. The post-PBL survey (see Appendix B) comprised of 20 Likert scale items with the same five points, as well as three open-ended items capturing students' perceptions regarding the PBL module and group learning. The additional questions that were included in the post-PBL survey were added to capture students' perceptions about the module itself, as those questions could not have been asked before its delivery. Internal reliability of this instrument was 0.91. The purpose of these two surveys was to compare students' perceptions before and after the PBL in general, as well as to capture their attitudes towards the PBL module used in this study.

Structured Student Reflections

At the conclusion of the PBL module, all students were asked to submit structured reflections (see Figure 4) that probed their perceptions of learning with the PBL module, to answer the second research question. The reflection was initiated by answering the following questions: what did I learn, what action will I take, and what new questions do I have, along with additional questions to expand student reflection.

Data analysis

Pretest-Posttest Analysis

Pretest scores were compared with the posttest scores using the dependent t-test, also known as the paired sample t-test, to determine whether there was a statistically significant difference between the scores. According to power analysis results conducted using G*Power for the sample size of 33, the effect size of 0.53 was needed to reject the null hypothesis (Faul et al., 2007). However, since 31 participants had completed the pretest-posttest instrument, effect size for that instrument was recalculated as 0.60 (Faul et al., 2007). Use of null hypothesis tests and consideration of statistical power has questionable utility in the context of a case study, given there was not a conceptualization of some broader population; however, it is instructive to see that a sample size of 33 should be able to detect a standardized mean difference of 0.41 (critical $p = 0.05$, power = 0.80, one-tail, pair sample t-test). This suggests that the within-case sample was large enough for stable estimation of growth in image critique skills.

Survey Analysis

Responses to Likert scale survey items were analyzed descriptively, examining means and standard deviations. Additionally, since the pre- and post-PBL surveys had the four same Likert scale items, those items were matched and compared by using a paired sample t-test, to determine whether there was a statistically significant difference between the means ($p < 0.05$). Open-ended items were analyzed qualitatively by using coding and categorization.

Structured Student Reflections Analysis

Content analysis was conducted first, as an iterative process that started with a superficial examination of the reflection responses, then reading, and interpretation, as well as organizing information into categories. Furthermore, peer debriefing was utilized. Thematic analysis was conducted to recognize patterns and emerging themes within the data (Bowen, 2009), which was compared with the codes and categories generated during the content analysis. This process was further organized through the use of a codebook (Guest et al., 2006). The codebook findings were cross-referenced with paired sample t-test results to merge qualitative and quantitative findings.

Results

The results are reported in this section by research question.

Research Question 1

A paired sample t-test was conducted to examine whether using PBL had an effect on the students' overall image critique skills revealed that the average image score at pretest was 12.52 (SD = 4.51), and 15.27 (SD = 4.74) at posttest. The statistically significant difference between the scores suggests that the PBL module improved overall image critique skills from pretest to posttest, $t(31) = -5.29$, $p < .05$. The 95%

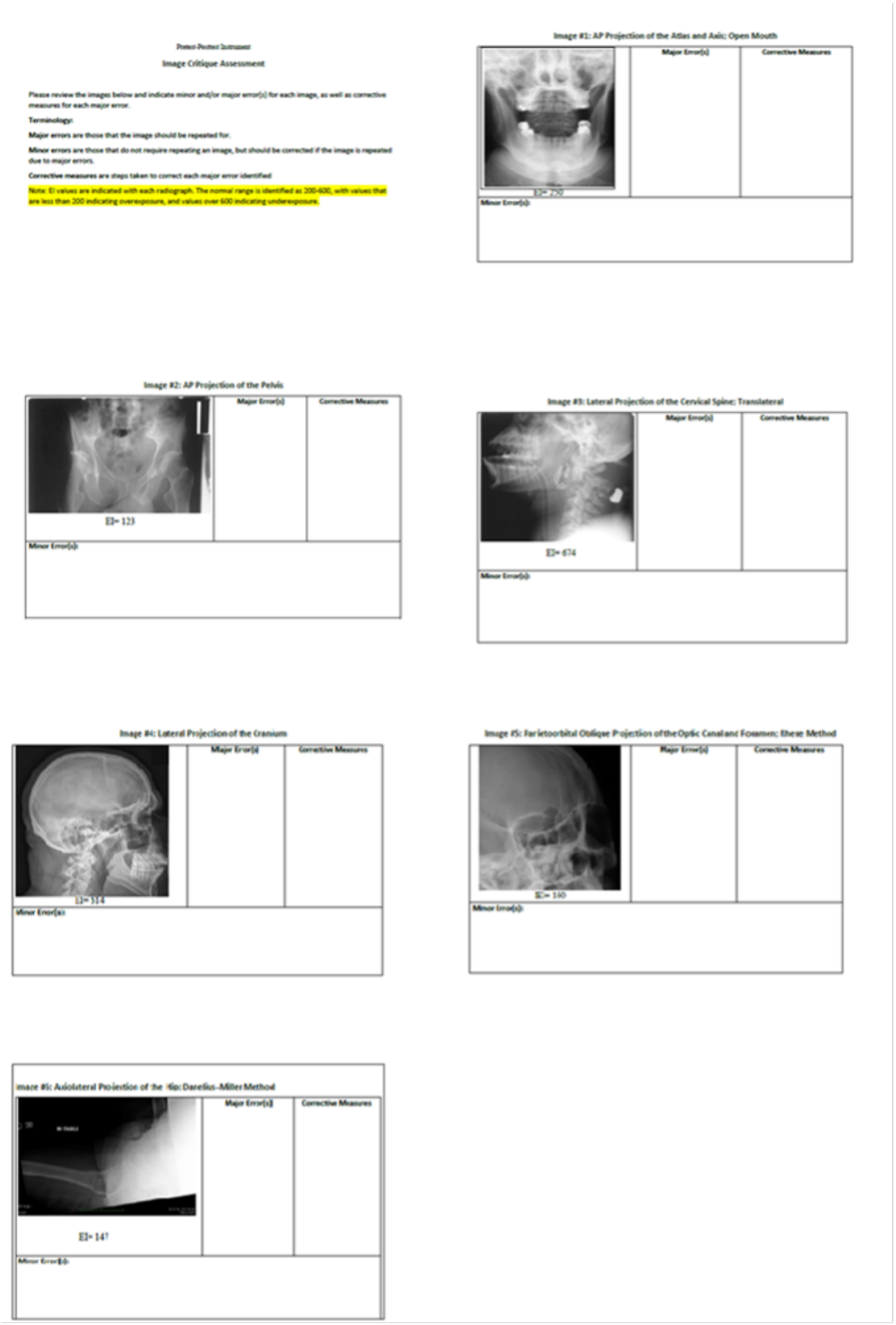


Figure 3. Pretest-posttest Instrument

confidence interval for the mean difference between the two time points was -3.81 to -1.69. Effect size estimate, expressed as g, was large (g = 0.94) (Hedges, 1981).

A separate paired sample t-test was conducted to examine whether using PBL had an effect on image critique skills related specifically to the image used in the PBL module. Students' average score captured by the pretest was 1.67 (SD = 0.78), and their score for the post-test was 3.00 (SD = 1.36). The results showed a statistically significant difference between pretest and posttest scores, suggesting that PBL significantly improved image critique skills related to the hip projection, $t(31) = -7.36$, $p < .05$. The 95% confidence interval for the difference in means ranged from -1.70 to -.96. Effect size estimate, expressed as g, was large (g=1.30) (Hedges, 1981).

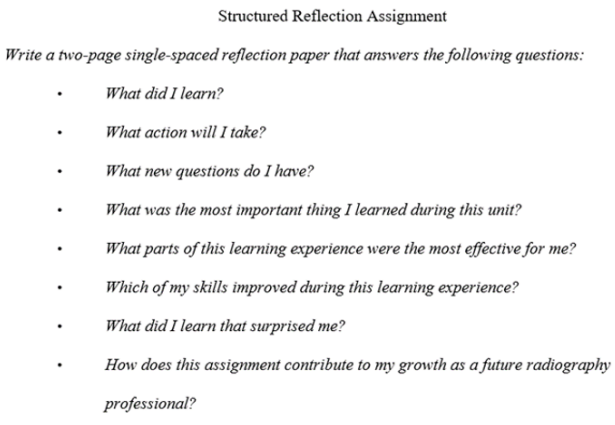
Research Question 2

To answer the second research question, responses to the Likert-type and open-ended items on pre- and post-PBL survey were analyzed and reported below, along with the results from the structured reflections

The overall mean score for the six Likert-type items on the pre-PBL survey was 4.08, indicating overall positive ratings above the 'agree' level. The highest rated item on the survey was "Image critique education is relevant to my future practice as a radiographer" (M = 4.88) and the lowest was "I had positive experiences related to learning through group projects in previous courses" (M = 3.21).

The overall mean for the 19 Likert-type items on the post-PBL survey was 4.10, also indicating generally positive ratings. The highest rated items were "Image critique education is relevant to my future practice as a radiographer" (M = 4.97) and the lowest was "This PBL module enhanced my ability to present in front of people" (M = 3.18).

There were four items that were used in both pre- and post-PBL survey. Table 1 presents the pre- and post-PBL survey mean scores and standard deviations associated with those items. A paired sample t-test was conducted to examine the differences between means on a pre- and post-PBL survey for these items. For the first item, the results indicated a statistically significant difference between pre- and post-survey, suggesting that students felt more prepared to critique images, $t(31) = -2.48$, $p < .05$. Effect size estimate, expressed as g, was small (g = 0.44) (Hedges, 1981). For the third survey item, results were also statistically significant between pre-and post-surveys suggesting that students perceived solving problems in a group as a good way to practice critiquing images, $t(31) = -2.01$, $p < .05$. Effect size estimate, expressed as g, was small (g = 0.38) (Hedges, 1981). No statistically significant differences were identified between pre- and post-survey results for the two remaining items.


Structured Reflection Assignment

Write a two-page single-spaced reflection paper that answers the following questions:

- *What did I learn?*
- *What action will I take?*
- *What new questions do I have?*
- *What was the most important thing I learned during this unit?*
- *What parts of this learning experience were the most effective for me?*
- *Which of my skills improved during this learning experience?*
- *What did I learn that surprised me?*
- *How does this assignment contribute to my growth as a future radiography professional?*

Figure 4. Structured Student Reflections

Students were asked to respond to the two open-ended items on the pre-PBL survey. The first item asked students to identify what they liked the most about learning in a group. The most common theme recognized in the responses to this question focused on hearing ideas and opinions of others. Similarly, the second theme identified discussing ideas and brainstorming with others, while the third theme included sharing workload and shared knowledge. On the other hand, three students did not identify anything that they liked about group learning.

Students were also asked to identify what they liked the least about learning in a group. The most common theme was uneven workload, followed by the theme that identified group work as distracting and unorganized. Three other themes that emerged were having opposing opinions, delivering presentations, assigning group member roles, and the time-consuming nature of group work. Lastly, liking everything about learning in a group formed another theme.

The post-PBL survey included three open-ended items. When asked what they liked the most about this PBL module, the most common theme was learning how to critique images, followed by knowledge gained, working in a group environment, and sharing of ideas and opinions. In addition to these four most common themes, a couple of students identified presentations and learning about the importance of image critique as something they liked the most, while one student responded with "n/a."

When asked to identify what they least liked about this PBL module, the most common themes identified in student responses were the time away from clinical, having to critique only one image in the PBL module, and group-related issues. Another theme was not being clear about what was expected, along with the time-consuming nature of the module. Lastly, responses that indicated that students liked everything about the PBL module resulted in another theme.

	Pre-PBL Survey *M*	Pre-PBL Survey *SD*	Post-PBL Survey *M*	Post-PBL Survey *SD*
How would you describe your preparedness to critique radiographic images?	3.68	0.60	4.03	0.66
Image critique education is relevant to my future practice as a radiographer.	4.84	0.45	4.97	0.18
The ability to collaborate with my peers is necessary in my future profession.	4.58	0.67	4.71	0.64
Solving problems in a group may be an effective way to practice image critique.	4.06	0.77	4.42	0.76

Table 1. Pre- and post-PBL survey mean scores and standard deviations

The third open-ended item asked the students to identified if this module changed their attitude toward learning in a group. One of the major themes that emerged was no attitude change, followed by a positive change, and finally, a negative change. Two categories were identified within the no attitude change theme. The first one was due to preference to work independently because of unequal participation associated with group projects, and the second was due to students who have always liked group projects and still did after this module.

Student responses to structured reflections are reported by question, to further explore perceptions in regards to learning with the PBL module. Four major themes related to "What did I learn?" question emerged. The first theme was related to learning image critique in general. One of the categories within this theme was learning more about image critique and how to be thorough when critiquing images. For example, one student wrote the following: "I think that this image critique lab has taught me how to thoroughly evaluate an image," while another one indicated the following: "I feel better equipped to go back and fix any of my own mistakes and critique myself if necessary." The second theme was focused on concepts related to the hip projection that was used in the PBL module. One student wrote: "I learned more about the translateral hip projection and the evaluation criteria that pertains to the projection." The third theme included skills gained that were not directly related to image critique. The first category within this theme included the development of a variety of skills that were utilized in the clinical setting. There were 16 comments that mentioned some of these various skills, including: "I learnd [sic] that my actions and decisions made as a professional have the ability to impact my patients in either a positive or negative way" and "knowledge that goes beyond performing a cross-table hip exam. I learned how important it is to communicate with fellow technologists." The fourth theme involved concepts learned that are a result of working in a group.

The first theme that emerged in responses to "What action will I take?" involved actions related to improving image critique skills. For example, one student indicated the following: "I will take actions to help improve not only my own image critiquing abilities but of those around me who ask my advice." Additionally, becoming more detail-oriented was outlined as an action. One student wrote, "I will thoroughly view the images before letting the patient go and sending the images to the radiologist" and "after carefully assessing

each image, I will have to make a decision on whether or not the image meets diagnostic quality." The next theme incorporated various actions pertinent to procedural aspects and patient care, and finally, conducting research. Comments within this category included: "the action to take would have been to go into the patient's room and verify the positioning and everything else was to your standards because when you take that image, you become responsible for it and the patient," and "I will never make the same mistakes that were made in the video we watched. Each and every patient deserves to be taken care of appropriately."

While five students responded that they did not have any new questions in response to "What new questions do I have?", the rest of the participants' responses were categorized in one of three themes. The first theme focused on questions related to poor image critique skills, including the following comments: "What causes the technologist to repeat for small errors, and not repeat when there is clearly a huge error that they did not repeat for the day before?" and "I am curious if techs get reprimanded for sending these kinds of images through. I also wonder if techs are re-taught positions that they seem to have forgotten or do not know how to do well." The second theme involved questions related to the implementation of this PBL module, and third theme was focused on questions about the axiolateral hip projection and those related to the ability to transfer skills learned during this module to other situations.

Three major themes emerged from responses to "What was the most important thing I learned during this unit?" The first theme involved image critique skills and it included two categories. The first category incorporated responses related to image critique skills, such as "the most important thing that I learned during this experience is that it is very important to know the proper evaluation criteria" and "the most important thing I learned during this unit, is how to approach an image critique scenario." The second category consisted of responses related to being thorough when critiquing images and included comments, such as "it is important to not glance at an image to see if it is good to send to the radiologist, but rather to really look to see if it meets all important evaluation criteria" and "the most important thing I learned during this unit was that you shouldn't just glance at an image and say, 'Yeah, that's fine.'" The second theme was learning a variety of skills related to procedural aspects of examinations and included responses, such as "the most important thing I learned during this unit is that the issue is not always positioning" and learning "that there is not always one way to do something." The third theme was improved image quality as a result of being more focused on the patient.

The answers to "What parts of this learning experience were the most effective for me?" were organized in three themes. The first theme was learning in a group. For example, one student wrote that "expanding ideas, knowledge, and critical thinking skills with classmates was an effective way of learning to think outside the box." Problem-solving approach emerged as the second theme, including responses that identified discussions, brainstorming, creating hypothesis and solutions, as well as extra time to spend on the problem afforded by this approach as effective ways of learning in this module, while the third theme included listening to presentations.

Students' answers to "Which of my skills improved during this learning experience?" resulted in five themes. The first theme indicated that students experienced an improvement in critical thinking and problem-solving skills, while the second pointed to image critique skills, as evident in the comments such as "my image critique skills definitely improved during this lab," and "I have already paid more attention critiquing all images I take." The next theme focused on the improvement of collaboration skills, while the fourth included improvement of communication skills, alongside leadership and critical thinking skills. The final theme focused on the skills related to hip procedure performance.

While five students wrote that nothing that they learned surprised them in response to "What did I learn that surprised me?," their peers' responses resulted in four themes. In the first theme, the effectiveness of working in a group and learning from others was identified. For example, one student wrote "I didn't think there would be as much to talk about and discuss as there actually was and that each group that presented would touch on a topic or bit of information that no one else had even mentioned." Being surprised by how much they actually liked the PBL process was another theme, while the third theme indicated that students were surprised that technologists approve poor-quality images. In the final theme, students identified how much they have learned during this module as surprising.

Five themes emerged from the answers to "How does this assignment contribute to my growth as a future radiography professional?" The first theme focused on improving students' skills related to patient care and image quality and it included responses such as "most importantly, I want to be a technologist that produces diagnostic images to the very best of my ability, while giving my patient the best care possible." The second theme identified improvement of image critique skills as a contributing factor. In the third theme, continued effort for professional development was recognized. Finally, students indicated that they developed problem-solving, critical thinking, and collaboration skills during this assignment, which they thought would influence their future careers.

Discussion

This section provides a summary of the study's findings by research question, and it includes implications, future research, and limitations.

Research Question 1

For this study, students' image critique skills were captured before and after the PBL module. Their scores improved significantly between pretest and posttest for overall image critique skills, as well as for image critique skills related specifically to axiolateral hip image, indicating that PBL is a viable instructional strategy for enhancing students' image critique skills in radiography. Posttest scores were significantly higher than the pretest scores, with large effect sizes for both overall image critique skills and skills related to critiquing axiolateral hip images. The effect size for overall image critique skills was 0.94, indicating that null hypothesis can be rejected, as an a priori power analysis established the effect size of 0.60. Furthermore, the effect size for the image critique skills related to the axiolateral hip image was 1.30, indicating an even greater difference between pretest and posttest scores, suggesting that students learned more about the hip image. The learning activities were designed around a PBL scenario based on the axiolateral projection of the hip, which naturally led students to research and learn more about this specific projection, while learning about image critique in general. In the future, a variety of images may be used during similar PBL modules, if an improvement in overall image critique skills is desired.

These findings related to the first research question are consistent with what previous research related to learning with PBL in nursing education concluded, which is that PBL is effective when critical thinking skills are evaluated using pretest-posttest design (Yuan et al., 2008; Gholami et al., 2016; Tiwari et al., 2006; Shin & Kim, 2012). However, these studies had a lecture group and a PBL group, which was not the case in this research.

Even though strong causal inference pertaining to PBL use was problematic given the lack of a control group (Shadish et al., 2002), these findings were bolstered via triangulation with the findings from the students' reflection in their responses to What did I learn question, as outlined in the results section above. More generally, the purpose of these data was to yield insights regarding the effectiveness of the PBL processes within radiography instruction, and investigate how PBL can fulfill radiography education goals to prepare students for their future careers. Skills such as critical thinking, problem-solving, and desire for lifelong learning are required in the radiography profession, and as such are an important part of the radiography curriculum. Typically, most of these skills are taught using lecture-based methods, even though other instructional methods that are learner-centered, such as PBL, may be better suited (Kowalczyk, 2011), especially as students do not get the opportunity to practice these skills when teacher-centered methods are utilized.

Research Question 2

Because students' perceptions regarding the use of PBL were investigated before and after the PBL module, these findings are presented separately, under research question 2.

In their clinical practice, radiographers are required to make critical decisions about the quality of radiographic images every day (Carlton et al., 2020). Therefore, it was not surprising that students' perceptions related to image critique education before PBL were positive, as this was the highest rated item on the pre-PBL survey. Conversely, their perceptions regarding past experiences related to learning through group projects were rather low, as only 36% responded above the agree level. Furthermore, when asked to identify what they liked the least about learning in a group before this PBL module, students' responses resulted in three most common themes, including uneven workload, unorganized nature of group learning, as well as opposing opinions. These past experiences may have had a negative impact on students' motivation to learn with PBL. This finding is supported by Levett-Jones (2005), who suggested that pre-nursing students preferred teacher-centered instruction for the same reason. Uneven workload, opposing opinions, having to deliver presentations, and the time-consuming nature of group work were identified as something that the students in this study disliked. Unfortunately, studies that focused on nursing students' perceptions related to PBL did not investigate students perceptions about group work prior to PBL, and therefore, this finding could not be compared to previous research.

The students' perceptions related to the importance of image critique were still positive after PBL, and were one of the highest rated Likert scale items on the post-PBL survey. While the students wrote that they liked learning how to critique images with PBL, sharing ideas and opinions with their peers and how much they have learned, when asked to identify what they liked the least, one of the common themes identified in the responses to the open-ended post-PBL survey items was time lost at clinical as they thought that would have a negative impact on their clinical grades. This finding is relevant for planning future implementations of PBL, which would need to be embedded in the clinical education seamlessly, to avoid this dissatisfaction.

Furthermore, the remainder of the comments that indicated limited satisfaction with this PBL module were tied to discomfort with working in a group, which was a repeating theme from the pre-PBL survey. However, these concerns may dissipate with having students select their groups (Klegeris & Hurren, 2011), especially when students already have established relationships with their peers. While

students' perceptions toward learning in a group remained the same for 13 students, it is important to note that nine students reported that this PBL module had a positive impact on their attitude. This is similar to what research focused on nursing students' attitudes found (Rideout et al. 2002; Smith & Coleman, 2008; Tiwari et al. 2006). Although difficulties related to transitioning to PBL were not explicitly reported by the students in this study, one of the most common themes identified in their comments related to group work indicated that they indeed had trouble adjusting, most likely due to being accustomed to lecture-based instruction. While it may be expected that these difficulties could gradually decrease after more experience with PBL, greater emphasis should be placed on preparing students for this transition (Kantar, 2013). Even though students in this study were introduced to PBL, it may be better to expand the introduction by starting with an assignment in which students learn more about PBL prior to implementation. Furthermore, starting with a micro PBL module may be a better approach, which is documented in the literature as a "posthole" unit (Ertmer & Glazewski, 2015).

To help determine if there was a change in students' perceptions after the PBL module, a comparison of the four items included in both pre- and post-PBL survey was used. When asked to rate their preparedness to critique radiographic images before and after PBL, students reported feeling better prepared after the PBL module. While this may be interpreted as inflated confidence because of higher level of satisfaction with PBL (Rideout et al., 2002), statistically significant difference between pretest and posttest and the large effect size indicated that the students were indeed better prepared for image critique after this PBL module. This finding is confirmed with the results from a study that concluded that nursing students who graduated from PBL programs felt better prepared for their clinical practice compared to their counterparts from conventional programs (Rideout et al., 2002).

Lastly, students perceived solving problems in a group as a good way to practice critiquing images, as evident in their ratings, which were significantly higher on the post-PBL survey. It is promising that students realized the potential benefits PBL might have on image critique skills, such as sharing of ideas during group discussions, distribution of the workload, as well as the self-directed nature of PBL. Even though this finding cannot be confirmed with that of other studies due to a lack of similar research, this was supported by student reflections, which reported learning more about image critique, how to be thorough when critiquing images, and learning as a result of working in a group, indicating that students indeed perceived PBL as a good way to practice image critique. However, the novelty effect needs to be taken into account while interpreting these higher rating (Hung, 2019). Offering another PBL module to the same group of students would have been useful in identifying if that was the case in this study.

PBL helped students develop problem-solving skills, as well as communication and collaboration skills, and self-directed skills, as evident in their reflections. Development of these skills is not only consistent with the goals of PBL (Hmelo-Silver, 2004), but is one of the goals set by radiography curricula (ASRT, 2022). Students mentioned that this PBL module contributed to their growth and that they have recognized the value of professional development and lifelong learning. These perceptions relate to one of the purposes of PBL, which is to promote responsibility for lifelong learning and continued professional growth (Barrows, 1994). Moreover, previous research that implemented PBL in nursing education found that self-directed learning skills and problem-solving were found to be equally developed using either PBL or lecture method (Choi et al., 2014; Gholami et al., 2016; Tiwari et al., 2006). While the development of self-directed learning skills may not be exclusive to PBL, it is worth noting that coupled with improved problem-solving, communication, and collaboration skills, PBL may be more advantageous to practicing image critique than lecture method in radiography.

Even though PBL seems to be advantageous in fulfilling radiography education goals, it requires a new paradigm, for which radiography instructors must be prepared. Mainly, instructors must be ready for a change from the passive transmission of knowledge from instructors to students, associated with traditional lecture-based instructional methods, which are prevalent in radiography education (Gosnell, 2010). Handling a change in classroom dynamics can be difficult for educators who are new to PBL. For example, the researcher/facilitator in this study found it challenging to continue with PBL and not to switch back to a lecture method when students were struggling with moving their learning forward. Therefore, preparing for challenges that a novice PBL instructor may encounter needs to be a part of planning for PBL.

The planning process for this PBL module was time-consuming and was not an easy task, despite training in PBL and in instructional design, as well as guidance and support researcher/facilitator received from expert designers and higher education professionals. In contrast, most radiography educators lack such extensive support, as evident in some of their perceived barriers to using PBL, including lack of resources, being unfamiliar with developing assessments to evaluate difficult concepts such as critical thinking, as well as lack of curriculum development skills (Kowalczyk, 2011). While the researcher/facilitator was able to overcome most of those difficulties due to support she had, she faced other challenges. First, assuming a facilitative role was not an easy transition to make. Even though engaging students and

initiating inquiry was not difficult, sustaining engagement and ensuring that students stay on track during discussions was challenging for only one facilitator, given the number of students. However, it is important to note that this PBL module was found to be effective in developing students' image critique skills, despite these difficulties. This is consistent with other research that demonstrated positive results using PBL with large classes without tutors, which was credited to good facilitation skills, addressing accountability, and workload distribution (Klegeris & Hurren, 2011; Woods, 1996). Second, delivering soft scaffolds as just-in-time instruction was challenging, since they could not be planned for. Lastly, being able to recognize when adaptations are necessary may be difficult for PBL facilitators. For example, in this study, revising learning activities, which involved eliminating one of the meetings because students were working ahead, was a necessary adaptation in this PBL module. This finding revealed the importance of allowing for adaptations to meet students' needs, which has also been recognized in the existing literature (Barab & Luehmann, 2003).

This study holds implications that could be useful to radiography educators tasked with planning PBL modules. Allowing enough time for the planning and designing the module with diligence, even though the nature of PBL makes it impossible to plan for all aspects of learning, is critical. Choosing an engaging problem that is moderately-structured, relevant, and meaningful to students is important to sustained student involvement, and should be taken seriously. When planning PBL for large classes, letting students self-select groups should be considered, as group dynamics may affect both learning outcomes and student perceptions related to PBL. Ensuring that students are prepared for their new roles associated with the PBL approach is also critical to its success. Therefore, educators should start small and design shorter PBL modules that allow students to adjust to the new demands of this student-driven approach before longer modules or curriculum-wide implementation is considered.

Another implication is the implementation of the PBL module designed for this study by the clinical faculty members at the researchers' institution. The original module has been revised based on the findings discussed above, which pointed to incorporating future modules as a part of the existing clinical curriculum to minimize students' dissatisfaction related to time that they lost when the module was delivered at the university. Additionally, this helped decrease instructor-to-student ratio, which was 33:1 during the original implementation, to allowing each group of three to five students to have their own facilitator. This has helped support sustained engagement and participation, with more frequent student check-ins (Ertmer & Simons, 2005; Ertmer & Glazewski, 2015). Furthermore, the revised PBL modules include use of a different image every week, due to the finding that showed the need for a variety of images, with hopes of improving students' overall image critique skills.

Future studies that replicate the design of this research could be utilized to validate and extend the findings discussed above. First, replicating this study with a pretest-posttest instrument that has improved psychometric features to better measure learning gains and allow for the procedures to calculate internal consistency would be useful. Addition of assessment tools to capture PBL gains, such as project scoring that evaluates collaboration skills, may also be included. Further improvements may include an addition of a control group, if the curriculum allows, as well as better preparing students for their new roles. Involving other faculty members to implement PBL and collect data is recommended to eliminate potential bias. Finally, this study could be replicated in a context other than image critique to add to understanding of how else PBL can be used in radiography education.

This study had its limitations. It was conducted with the only cohort that was available in the radiography program, which limits external validity of this research, as well as internal validity, since there was no control group. Even though the results of this study might not be generalizable to all radiography programs, by describing a phenomenon in great detail, it is expected that the study's conclusions may be transferable to other contexts, times, and situations (Lincoln & Guba, 1985). The concept of transferability deals with the degree to which this can be achieved. While the reader decides if findings are transferable, this cannot be done without detailed description of the context of the study (Brantlinger et al., 2005). An additional limitation was due to self-reported data collected from surveys and reflections, which has a limitation bias that is inherent in self-reporting (Hmelo-Silver, 2004; Kopcha & Sullivan, 2007), as well as recall bias and socially desirable response (Tiwari et al., 2006). Finally, assessment of PBL was difficult, which has been recognized in the literature (Savin-Baden, 2004). Developing an instrument to measure complex constructs, such as image critique skills, was especially challenging.

Conclusion

Conclusions of this study provide a unique insight into the use of PBL in radiography education and could benefit radiography educators and instructional designers who work in similar contexts as described above. Radiography educators and instructional designers are in charge of making design decisions that can impact student achievement, as well as the quality of students' learning experience, and as such should rely on evidence-based research results, like those described above. However, it is important to note that additional research that uses assessment appropriate to

measuring complex constructs such as image critique skills is necessary before definitive conclusions regarding the use of PBL in radiography can be made.

References

Albanese, M. A., & Dast, L. (2014). Problem-based learning: Outcomes evidence from the health professions. Journal on Excellence in College Teaching, 25(3-4), 239-252.

Albanese, M.A., & Mitchell, S. (1993). Problem based learning: Review of literature of its outcomes and implementation issues. Academic Medicine, 68(3), 52-81.

Álvarez-Cruces, D., Sáez-Delgado, F., & López-Angulo, Y. (2020). Systematic review of self-regulated learning in health sciences students. Revista Cubana de Educación Medica Superior, 34(4), 40-57. https://www.medigraphic.com/cgi-bin/new/resumenI.cgi?IDARTICULO=100576

American Society of Radiologic Technologists. (2022). Radiography curriculum. Retrieved from https://www.asrt.org/educators/asrt-curricula/radiography

Arrue, M. M., Ruiz de Alegría, B. B., Zarandona, J. J., & Hoyos Cillero, I. I. (2017). Effect of a PBL teaching method on learning about nursing care for patients with depression. Nurse Education Today, 52(17), 109-115. https://doi.org/10.1016/j.nedt.2017.02.016

Asghar, A., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting stem education in secondary science contexts. Interdisciplinary Journal of Problem-based Learning, 6(2), 85-125. https://doi.org/10.7771/1541-5015.1349

Baker, C. M. (2000). Problem-based learning for nursing: Integrating lessons from other disciplines with nursing experiences. Journal of Professional Nursing, 16(5), 258-266. https://doi:10.1053/jpnu.2000.9461

Barab, S. A., & Luehmann, A. L. (2003). Building sustainable science curriculum: Acknowledging and accommodating local adaptation. Science Education, 87(4), 454-467. https://doi.org/10.1002/sce.10083

Barrows, H. S. (1994). Practice-based learning. Springfield, IL: Southern Illinois University.

Beers, G. (2005). The effect of teaching method on objective test scores: Problem-based learning versus lecture. Journal of Nursing Education, 44(7), 305-309. https://doi.org/10.3928/01484834-20050701-03

Belland, B. R., Kim, C., & Hannafin, M. J. (2013). A framework for designing scaffolds that improve motivation and cognition. Educational Psychologist, 48(4), 243-270. https://doi.org/10.1080%2F00461520.2013.838920

Bowen, G. A. (2009). Document analysis as a qualitative research method. Qualitative Research Journal, 9(2), 27-40. https://doi.org/10.3316/QRJ0902027

Brantlinger, E., Jimenez, R., Klingner, J., Pugach, M., & Richardson, V. (2005). Qualitative studies in special education. Exceptional Children, 71(2), 195-207. https://doi:10.1177/001440290507100205

Carlton, R. R., Adler, A. M, & Balac, V. (2020). Principles of radiographic imaging: An art and a science (6th ed.). Boston, MA: Cengage.

Carroll, C., Patterson, M., Wood, S., Booth, A., Rick, J., & Balain, S. (2007). A conceptual framework for implementation fidelity. Implementation Science, 2(40), 8-17. https://doi:10.1186/1748-5908-2-40

Carvalho, D., Azevedo, I. C., Cruz, G., Mafra, G., Rego, A., Vitor, A. F., Santos, V., Cogo, A., & Ferreira Júnior, M. A. (2017). Strategies used for the promotion of critical thinking in nursing undergraduate education: A systematic review. Nurse Education Today, 57, 103-107. https://doi:10.1016/j.nedt.2017.07.010

Choi, E. E., Lindquist, R. I., & Song, Y. A. (2014). Effects of problem-based learning vs. traditional lecture on Korean nursing students' critical thinking, problem-solving, and self directed learning. Nurse Education Today, 34(1), 52-56. https://doi:10.1016/j.nedt.2013.02.012

Derry, S. J., Hmelo-Silver, C. E., Nagarajan, A., Chernobilsky, E., & Beitzel, B. D. (2006). Cognitive transfer revisited: Can we exploit new media to solve old problems on a large scale? Journal of Educational Computing Research, 35(2), 145–162. https://doi.org/10.2190/0576-R724-T149-5432

Ertmer, P. A., & Glazewski, K. D. (2015). Essentials for PBL implementation: Fostering collaboration, transforming roles, and scaffolding learning. In P. A. Ertmer (Ed.), Essential readings in problem-based learning: Purdue University Press.

Ertmer, P. A., & Glazewski, K. D. (2019). Scaffolding in PBL environments: Structuring and problematizing relevant task features. In M. Moallem, W. Hung, & N. Dabbagh (Eds.), The Wiley handbook of problem-based learning. NJ: John Wiley & Sons, Inc.

Ertmer, P. A., & Simons, K. D. (2005). Scaffolding teachers' efforts to implement problem-based learning. International Journal of Learning, 12(4), 319-328.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods, 39(2), 175-191. https://doi:10.3758/BF03193146

Fraenkel, J., Wallen, N., & Hyun, H. H. (2011). How to design and evaluate research in education. New York:

McGraw-Hill.

Gholami, M., Moghadam, P. K., Mohammadipoor, F., Tarahi, M. J., Sak, M., Toulabi, T., & Pour, A. H. (2016). Comparing the effects of problem-based learning and the traditional lecture method on critical thinking skills and metacognitive awareness in nursing students in a critical care nursing course. Nurse Education Today, 45(17), 16-21. https://doi:10.1016/j.nedt.2016.06.007

Goodnough, K., & Cashion, M. (2010). Exploring problem-based learning in the context of high school science: Design and implementation issues. School Science and Mathematics, 106(7), 280-295. https://doi:10.1111/j.1949-8594.2006.tb17919.x

Gosnell, S. (2010). Teaching and assessing critical thinking in radiologic technology students (Doctoral dissertation). Retrieved from Electronic Theses and Dissertations. (4244) https://stars.library.ucf.edu/cgi/viewcontent.cgi?article=5244&context=etd

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. Field Methods, 18(1), 59-82. https://doi:10.1177/1525822X05279903

Hedges, L. (1981). Distribution theory for Glass's estimator of effect size and related estimators. Journal of Educational Statistics, 6(2), 107-128. https://doi.org/10.2307/1164588

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16(3), 235-266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E., & Ferrari, M. (1997). The problem-based learning tutorial: Cultivating higher order thinking skills. Journal for the Education of the Gifted, 20(4), 401-422. https://doi:10.1177%2F016235329702000405

Hung, W. (2019). Problem design in PBL. In M. Moallem, W. Hung, & N. Dabbagh (Eds.), The Wiley handbook of problem-based learning. NJ: John Wiley & Sons, Inc.

Jin, J., & Bridges, S. (2016). Qualitative research in PBL in health sciences education: A review. Interdisciplinary Journal of Problem-Based Learning, 10(2), 156-182, https://doi:10.7771/1541-5015.1605

Kantar, L. (2014). Incorporation of constructivist assumptions into problem-based instruction: A literature review. Nurse Education in Practice, 14(3), 233-241. https://doi.org/10.1016/j.nepr.2013.08.010

Kelly, O. C., & Finlayson, O. A. (2007). Providing solutions through problem-based learning for the undergraduate 1st year chemistry laboratory. Chemistry Education Research and Practice, 8(3), 347-361. https://doi:10.1039/B7RP90009K

Klegeris, A., & Hurren, H. (2011). Impact of problem-based learning in a large classroom setting: Student perception and problem-solving skills. Advances in Physiology Education, 35(4), 408-415. https://hdoi:10.1152/advan.00046.2011

Kopcha, T. J., & Sullivan, H. (2007). Self-presentation bias in surveys of teachers' educational technology practices. Educational Technology Research and Development, 55(6), 627-646. https://doi.org/10.1007/s11423-006-9011-8

Kowalczyk, N. (2011). Review of teaching methods and critical thinking skills. Radiologic Technology, 83(2), 120-132. http://www.radiologictechnology.org/content/83/2/120.long

Kowalczyk, N. (2012). Facilitating the integration of problem-based learning in radiologic science education: The role of the educator. Radiologic Science & Education, 17(1), 3-9.

Levett-Jones, T. L. (2005). Self-directed learning: Implications and limitations for undergraduate nursing education. Nurse Education Today, 25(5), 363-368. https://doi.org/10.1016/j.nedt.2005.03.003

Lincoln, Y. S. & Guba, E. G. (1985). Naturalistic inquiry. Newbury Park, CA: Sage Publications.

Mpalanyi, M., Nalweyiso, I. D., & Mubuuke, A. G. (2020). Perceptions of radiography students toward problem-based learning almost two decades after its introduction at Makerere University, Uganda. Journal of Medical Imaging and Radiation Sciences, 51(4), 639–644. https://doi.org/10.1016/j.jmir.2020.06.009

National Council on State Board of Nursing. (2017). NCLEX and other exams. Retrieved September 17, 2017, from https://www.ncsbn.org/nclex.htm

Ozogul, G., & Sullivan, H. (2009). Student performance and attitudes under formative evaluation by teacher, self and peer evaluators. Educational Technology Research and Development, 57(3), 393-410. https://www.jstor.org/stable/40388636

Papinczak, T., Young, L., Groves, M., & Haynes, M. (2007). An analysis of peer, self, and tutor assessment in problem-based learning tutorials. Medical Teacher, 29(5), 122-132. https://doi.org/10.1080/01421590701294323

Reynolds, H. L. & Kearns. K. D. (2017). A planning tool for incorporating backward design, active learning, and authentic assessment in the college classroom. College Teaching, 65(1), 17-27. https://doi.org/10.1080/87567555.2016.1222575

Rideout, E., England-Oxford, V., Brown, B., Fothergill-Bourbonnais, F., Ingram, C., Benson, G., Ross, M., & Coates, A. (2002). A comparison of problem-based and conventional curricula in nursing education. Advances in Health Sciences Education: Theory and Practice, 7(1), 3-17. https://

doi.org/10.1023/a:1014534712178
Savin-Baden, M. (2004). Understanding the impact of assessment on students in problem-based learning. Innovations in Education and Teaching International, 41(2), 223-233. https://doi.org/10.1080/1470329042000208729
Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). Experimental and quasi-experimental designs for generalized causal inference. Boston, NY: Houghton Mifflin.
Shin, I., & Kim, J. (2013). The effect of problem-based learning in nursing education: A meta
analysis. Advances in Health Sciences Education, 18(5), 1103-1120. https://doi.org/10.1007/s10459-01v2-9436-2
Smith, L., & Coleman, V. (2008). Student nurse transition from traditional to problem-based
learning. Learning in Health & Social Care, 7(2), 114-123. https://doi.org/10.1111/j.1473-6861.2008.00177.x
Takayoshi, T., Naomi, T., Kengo, K., Hidenobu, K., & Katsuhiko, O. (2016). Problem-based learning for radiological technologists: A comparison of student attitudes toward plain radiography. BMC Medical Education, 161, 1-7. https://doi.org/10.1186/s12909-016-0753-7
Tiwari, A., Lai, P., So, M., & Yuen, K. (2006). A comparison of the effects of problem-based
learning and lecturing on the development of students' critical thinking. Medical Education, 40(6), 547-554. https://doi.org/10.1111/j.1365-2929.2006.02481.x
Woods, D. R. (1996). Problem-based learning for large classes in chemical engineering. New Directions for Teaching and Learning, 1996(66), 91-99. https://doi.org/10.1002/tl.37219966813
Yin, R. K. (2014). Case study research: Design and methods (5th ed.). Los Angeles, CA: SAGE.
Yuan, H., Kunaviktikul, W., Klunklin, A., & Williams, B. A. (2008). Improvement of nursing students' critical thinking skills through problem-based learning in the People's Republic of China: A quasi-experimental study. Nursing and Health Sciences, 10(1), 70-76. https://doi.org/10.1111/j.1442-2018.2007.00373.x

Vesna Balac is an Assistant Professor, Radiography Program Director, and Radiologic Sciences Department Chair at Indiana University Northwest in the College of Human and Health Services.

Gamze Ozogul is an Associate Professor of Instructional Systems Technology at Indiana University in School of Education.

Appendix A

Image Critique Pre-PBL Survey

By signing the informed consent form, you agreed to participate in this survey. Your participation in this survey is voluntary and you can change your mind and decide not to complete the survey at any time. Deciding not to participate will not result in any penalty and will not affect your relationship with the radiography program. If you feel uncomfortable or you do not want to answer a particular question, you can omit that question and complete the remaining questions. Your responses will be collected anonymously and results will be presented in aggregate form.

Please take the time to read each question/statement carefully and respond with your honest feedback selecting one of the choices below.

1. How would you describe your preparedness to critique radiographic images?

(1 =very inadequate; 2=inadequate; 3=neither adequate nor inadequate; 4=adequate and 5=very adequate)

2. Image critique education is relevant to my future practice as a radiographer.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

3. The ability to collaborate with my peers is necessary in my future profession.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

4. I have taken college-level courses that incorporated group projects.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

5. I had positive experiences related to learning through group projects in those courses.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

6. Solving problems in a group may be an effective way to practice image critique.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

7. What do you like the most about learning in a group?

8. What do you like the least about learning in a group?

Appendix B

Image Critique Post-PBL Survey

By signing the informed consent form, you agreed to participate in this survey. Your participation in this survey is voluntary and you can change your mind and decide not to complete the survey at any time. Deciding not to participate will not result in any penalty and will not affect your relationship with the radiography program. If you feel uncomfortable or you do not want to answer a particular question, you can omit that question and complete the remaining questions. Your responses will be collected anonymously and results will be presented in aggregate form.

Please take the time to read each question/statement carefully and respond with your honest feedback selecting one of the choices below.

1. How would you describe your preparedness to critique radiographic images AFTER this PBL module?

(1 =very inadequate; 2=inadequate; 3=neither adequate nor inadequate; 4=adequate and 5=very adequate).

2. Image critique education is relevant to my future practice as a radiographer.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

3. This PBL module helped activate my prior knowledge related to image critique.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

4. This PBL module helped me identify areas of weaknesses related to image critique.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

5. This PBL module helped me improve my areas of weaknesses related to image critique.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

6. This PBL module enhanced my ability to present in front of people.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

7. This PBL module helped improve my problem solving skills in general.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

8. This PBL module helped me develop confidence in self-directed learning.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

9. This PBL module was helpful in developing my information synthesizing skills.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

10. This PBL module motivated me to learn more about image critique on my own.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

11. The case used for this PBL module kept me interested in learning how to critique radiographic images.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

12. This PBL module helped me correct my misconceptions related to image critique concepts.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

13. I learned useful information not directly related to image critique during this PBL module.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

14. Group discussions during PBL module helped my understanding of image critique.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

15. The ability to collaborate with my peers is necessary in my future profession.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

16. Solving problems in a group is an effective way to practice image critique.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

17. My group worked well together.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

18. I contributed meaningfully to the group discussions.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

19. I am satisfied with this PBL module.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

20. I would like to learn other concepts using problem-based learning.

(1=strongly disagree, 2=disagree, 3= neither agree or disagree, 4=agree, 5=strongly agree)

Please answer the following questions:

21. What did you like the most about this PBL module?

22. What did you like the least about this PBL module?

23. Did this learning module change your attitude toward learning in a group? Please explain.