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ABSTRACT

To date, there are currently many variations of inquiry-based instruction including problem-based learning (PBL), lecture prior to problem solving, and case-based learning (CBL). While each claim to support problem-solving, they also include different levels of student- centeredness and instructor support. From an educational perspective, further clarity is needed to determine which model best supports learning outcomes such as conceptual knowledge, causal reasoning, and self-efficacy. While various meta-analyses have been conducted to ascertain how inquiry-based instruction compares with lecture-based approaches, there are few studies that directly compare these methods. To address this gap, this study looked at the effects of PBL, lecture prior to problem-solving, and CBL on students conceptual knowledge, causal reasoning, and self-efficacy (N = 96). While no significant difference was found on self-efficacy, the results found that learners in the PBL group performed highest on conceptual knowledge. In terms of causal reasoning, the PBL group outperformed other conditions on correctly identified connections. However, the PBL condition also had the highest number of incorrectly identified concepts. Implications for theory and practice are also discussed.

Keywords: inquiry-basedlearning;inquiry-basedinstruction;case-basedlearning;problem-basedlearning;project-basedlearning

Introduction

In workplace contexts, individuals often encounter ill-structured problems that have no readily prescribed solutions (Jonassen, 1997). Practitioners rely on their conceptual domain knowledge, problem space understanding, and causal reasoning to generate a solution for these complex problems (Hmelo-Silver, 2013). Causal reasoning during solution generation is especially critical because it requires an individual to not only identify the important variables, but also their relationships and dependencies within the problem space. Given the types of issues that practitioners face, classroom contexts have explored instructional strategies that allow students to encounter and solve ill-structured problems. Although there are many variations of these instructional strategies, they are often described as "inquiry-based instruction" (Loyens & Rikers, 2011) and designed to facilitate students' development of problem-solving competencies such as causal reasoning (Lazonder & Harmsen, 2016; Loyens, Jones, Mikkers, & van Gog, 2015). These instructional strategies are typically based on situated learning theory and use cases as a catalyst for problem-solving (Dabbagh & Dass, 2013; Hmelo-Silver, Duncan, & Chinn, 2007; Lazonder & Harmsen, 2016). Rather than considering learners to be passive recipients of information, these approaches often espouse degrees of student-directed learning because learners are afforded the opportunity to be active agents in the learning process while instructors adopt a more facilitative role (Herrington, Reeves, & Oliver, 2014; Loyens & Rikers, 2011). When compared with more didactic approaches, inquiry-based instruction also engenders higher gains in self-efficacy as students engage in problem-solving (S. W. Brown et al.2013; Dunlap, 2005).

There are currently many inquiry-based instructional strategies that ask learners to solve a contextualized case. Barrows (1986) argues that these varying approaches fall within a continuum in regards to problem openness and self-directed learning (p. 482). In terms of self-directed learning

(SDL), instructional strategies may be (a) student-directed learning, (b) partially student- and teacher-directed learning, or (c) teacher-directed learning. Problem-based learning (PBL), adopting a more student-directed learning perspective, requires learners to solve ill-structured problems prior to being taught the required content knowledge by the instructor (Barrows & Tamblyn, 1980). In the partial student and teacher approach, "teachers may start the inquiry with a short benchmark lesson" (Lazonder & Harmsen, 2016, p. 705) before students engage in inquiry. In this lecture prior to problem-solving approach, learners are first taught the content by the instructor and later asked to resolve the case. Finally, case-based learning (CBL) is a common application of the teacher-directed learning approach described by Barrows. This strategy is used in many business schools and centers instruction around a single problem. In contrast to the other two strategies, CBL focuses more on an instructor-driven discussion of the case with the student (Williams, 1992). Although these approaches have differences, educators can use each one to facilitate how learners conceptualize the problem space and identify the cause-effect relationships needed to solve the ill-structured case.

To date, research shows that such inquiry-based instructional strategies are generally effective in helping students establish domain conceptual knowledge and problem-solving skills (Lazonder & Harmsen, 2016; Loyens et al. 2006; Walker & Leary, 2009). However, there is still a significant debate about how to best implement inquiry-based instruction methods (Albanese & Mitchell, 1993; Kirschner et al, 2006; Kirschner & van Merriënboer, 2013). This debate stems, in part, from the imprecision in classifying the inquiry-based instructional models used in previous studies (Loyens & Rikers, 2011; van Merriënboer, 2013; Walker & Leary, 2009). Useful parameters for demarcating the differences between these approaches to inquiry-based instruction include the degree of student-directed learning and the role of the instructor (Barrows, 1986). In Barrows' (1986) taxonomy, PBL is high in student-directed learning whereas CBL is low. These parameters thus determine the responsibility of instructors and students in terms of who takes the lead during the learning process. However, these parameters may be confounding factors because different inquiry-based instructional approaches vary in the level of cognitive processing required during the learning process. Hung (2011) suggested that "these varying degrees of cognitive demand and psychological engagement could produce different degrees of impact on various aspects of learning outcomes" (p. 533). Differences may also emerge in terms of learners' affective gains in self-efficacy, which can be defined as an individual's assessment of their ability for a given activity (Dunlap, 2005)

Despite the increased attention to inquiry-based instruction, there is still a paucity of research that directly compares inquiry-based implementation types and their effects on student learning outcomes. The above distinctions have implications for both research and practice. From a research standpoint, the assumption that all of these approaches are equally effective potentially conflates the field's understanding of how much directed problem-solving students can be expected to manage. Addressing this gap thus has implications for our understanding of cognitive load and scaffolding. This lack of clarity can be also confounding to educators attempting to discern which inquiry-based model best supports the development of conceptual knowledge and problem-solving skills within their classrooms. This is especially important as school initiatives are increasingly exploring inquiry-based instruction as an alternative to traditional lecture learning (Lazonder & Harmsen, 2016; Wijnen et al., 2017). To benefit researchers and practitioners, rigorous empirical evidence is needed to verify and support successful implementations of inquiry-based instruction.

To address this research need, this study first distinguishes between theoretical and empirical underpinnings of PBL, lecture prior to problem-solving, and CBL through the lens of the Barrows (1986) continuum. We also review the limited research that has attempted to compare the effects of these instructional methods on problem-solving skills, especially as it relates to skills in causal reasoning. We then present a study that compares the effects of different inquiry-based instruction on students' conceptual knowledge, problem-solving skills (causal reasoning), and perceived self-efficacy in problem-solving. We conclude the study with a discussion of the findings and implications for implementing inquiry-based instruction.

Literature Review

Situated Learning Theory Using Cases

In information dissemination models, the objective of instruction is often to improve conceptual understanding and recite prescribed correct answers by means of standardized tests (Eseryel et al., 2013; Herrington et al., 2014; Jonassen, 1991). These models are frequently focused on attainment of a conceptual understanding that emphasizes explicit forms of knowledge (Rittle-Johnson et al., 2001). While these traditional forms of instruction served as a means to assess rote memorization, research found that they were limited in their ability to adequately prepare learners for the complex problem-solving skills that practitioners often employ, such as core variables identification, causal relationships articulation, and solution generation (Hmelo-Silver et al., 2007).

To better support higher order learning, theorists have advocated for an approach known as inquiry-based instruction in which learners have the opportunity to solve authentic, ill-structured problems (Lazonder & Harmsen, 2016; Loyens & Rikers, 2011). This strategy is largely based on situated learning theory (J. S. Brown et al., 1989) and asks students to solve an ill-structured case similar to the types of issues that practitioners face (Dabbagh & Dass, 2013). In contrast to more didactic approaches to education, learners are required to engage in problem representation and solution generation while the instructor is more focused on facilitating how learners define the variables, make inferences, and form predictions within the broader problem space (Savery, 2006; Strobel & van Barneveld, 2009). As students solve the cases presented to them, they are not only required to identify the germane concepts of the problem space, but also identify their relationships. In these learning contexts, Eseryel et al. (2013) assert that causal representations shed light on how learners understand the nature of dependencies between variables and thus go beyond the identification of an abstract relation. As students learn to identify the cause and effect relationships when generating solutions, they become engaged in deeper processing of the problem space (Hmelo-Silver & Barrows, 2008).

Shared characteristics of PBL, Lecture-Prior to Problem-solving, and CBL

To date, there are multiple approaches to implement inquiry-based instruction within classroom contexts. One of the most prominent forms of this strategy is problem-based learning (PBL) which prescribes that learners solve ill-structured problems as they engage in causal reasoning with peers. McMaster University in Canada and Maastricht in the Netherlands are often cited as pioneers in PBL. In 1969, McMaster University first implemented PBL within its medical curriculum and Maastricht University (then named State University of Limburg) soon followed in 1974. Over time, Barrows and Tambyn (1980) further advocated for PBL as a way to improve the more complex reasoning skills needed in clinical settings. Since then, PBL has been widely implemented across the health sciences and used in various disciplines within higher education and K-12 settings. These include business (Tawfik, 2017; Tawfik & Jonassen, 2013), pre-service teaching (Ertmer et al., 2014), STEM (S. W. Brown et al., 2013; deChambeau & Ramlo, 2017), and others.

While PBL has a prescribed set of procedures, theorists (Herrington et al., 2014; Loyens & Rikers, 2011) observed that adaptations have emerged as educators apply the problem-solving principles given their unique contextual advantages or constraints. Specifically, lecture prior to problem-solving (Lazonder & Harmsen, 2016) and CBL (Loyens & Rikers, 2011) are other common approaches of inquiry-based instruction that have recently gained popularity among educators. Under the conceptual umbrella of inquiry-based instruction, these approaches often share some variation of the following (Barrows & Tamblyn, 1980; De Graaf & Kolmos, 2003; Walker & Leary, 2009):

- Ill-structured problem—Learners are presented with a problem that is similar to what practitioners are asked to solve. While the complexity of the problem may be different, the contextualized problem affords many possible solutions given its contextual constraints.

- Case-structured curriculum—Rather than a list of topics, classroom concepts are organized around a case. In doing so, learners develop a case-based structure through which to organize their memory.

- Collaborative learning—Learners work collaboratively within groups (usually 3-6 students) to solve the problem. The collaborative process allows students to learn from each other as they present, justify, and negotiate ideas needed to solve the ill-structured case.

- Reflective learning—Students are asked to reflect upon their experiences after they have solved the problem.

- Self-directed learning—Learners are responsible for defining the causes of the problem and seeking out a potential solution. Instructors facilitate student inquiry rather than prescribe a solution path to solve the problem.

Despite their differences, these various inquiry-based instruction approaches often require students to solve an ill-structured problem that has different possible reasoning paths and multiple solutions. Specifically, the students identify the critical variables, generate and verify hypotheses, and then propose and evaluate solutions (Hmelo-Silver, 2004).

In addition to the common components described earlier, PBL, lecture prior to problem-solving, and CBL also purport to engender self-efficacy through problem-solving (Akcaoglu, Gutierrez, Hodges, & Sonnleitner, 2016). Self-efficacy is defined as the belief in one's ability to successfully complete the requisite actions for a given task (Bandura, 1997, p. 3). Brown and colleagues (2013) further argue that if "students' academic experiences are unsuccessful, then their self-efficacy is diminished, decreasing the likelihood of future engagement in a discipline" (p. 73). Given that inquiry-based instruction often poses ill-structured problems to students, self-efficacy is critical to complex problem-solving and plays a central role in determining whether an individual will persist in light of encountered challenges (S. W. Brown et al., 2013; Scott, 2014). Self-efficacy is also important for inquiry-based instruction by indicating how and when an instructor needs to intervene as students problem-solve. However, it is unclear the degree to which self-efficacy is influenced by varying degrees of instructor involvement during inquiry-based instruction.

Differences among PBL, Lecture Prior to Problem-Solving, and CBL

The directedness of the learning, defined as the distribution between instructor-directed and student autonomy (van Merriënboer, 2013), is another characteristic differentiating PBL, lecture prior to problem-solving, and CBL. PBL is considered high in student-directed learning because students function autonomously and the instructor scaffolds based on emergent needs (Jonassen, 1997; Loyens et al., 2015). Alternatively, lecture prior to problem-solving and CBL deviate from PBL in terms of how much the instructor is responsible for dissemination of knowledge. In contrast to PBL, lecture prior to problem-solving asks learners to solve the problem in groups after the instructor presents them with content and materials (Lazonder & Harmsen, 2016). This approach is more in line with Barrows' (1986) description of the teacher-directed approach, which emphasizes knowledge application from the given lecture rather than complete learner autonomy. Finally, CBL advocates that the instructor provides a more substantial role in directing students as they examine the interdependencies of concepts embedded within the problem space. In this form of teacher-directed learning, an instructor often facilitates a discussion about the ill-structured problem and engages in open dialogue with the students about how the problem could be solved (Dabbagh & Dass, 2013; Jonassen, 2011). The hallmarks of studying under CBL are a lower emphasis on student-directed learning and an increased emphasis on instructor scaffolding (Thistlethwaite et al., 2012; Williams, 1992).

The various approaches to self-directed learning among PBL, lecture prior to problem-solving, and CBL have important implications for instructors and researchers (Wijnia et al., 2014) in terms of the depth of cognitive processing and perceived levels of self-efficacy. For instance, in the PBL model, causal reasoning and decision-making is primarily conducted by the students. Therefore, this high level of student-directed learning requires both student-led knowledge acquisition and application towards a problem, which many argue results in deeper forms of understanding (Jonassen, 2011; Walker & Leary, 2009). Since an instructor serves in more of a facilitator role in the PBL model, research finds that students may also attain higher levels of self-efficacy given that they are the primary driver of their instruction (S. W. Brown et al., 2013). Indeed, other studies have confirmed that quality PBL facilitators who give the proper amount of guidance produce higher learning outcomes (Chng et al., 2011). Additional studies suggest that, even when PBL students perceive lower levels of self-efficacy (Yadav et al., 2011), they achieve higher learning gains than learners who studied under lecture-based approaches (Chng et al., 2011; Loyens et al., 2015).

Barrows and Tambyn (1980) classified other variations of inquiry-based instruction in terms of degree of inquiry. In lecture prior to problem-solving, inquiry activities related to information gathering inquiry and independent causal reasoning are not as acute when compared with PBL. Possibly, the combination of lecture and problem-solving better accounts for cognitive load limits due to less responsibility in initial knowledge acquisition while also allowing opportunities for solution generation. In order to better manage cognitive load and build self-efficacy, one might argue that lecture prior to problem-solving is more suitable for instructional situations where applications of content knowledge are the primary instructional goal or learners' cognitive maturity is lower. Similar to PBL, research suggests that students attain higher levels of self-efficacy in lecture prior to problem-solving compared to didactic-based approaches (Schaffer, Chen, Zhu, & Oakes, 2012; Wang, Huang, & Hwang, 2016). Studies also find that learning outcomes may be improved when lectures are given prior to problem-solving in terms of meaning-making (Smith, 2016), critical thinking (Wang et al., 2016), and collaborative problem-solving (Huh et al., 2014; Lee et al., 2015). It is further argued that learners have higher degrees of confidence and self-efficacy in lecture prior to problem-solving contexts given that they are more focused on executing the concepts the instructor has shared during lecture (Tiwari et al., 2006).

Lastly, CBL presents learners with real world scenarios that depict the complexities of a case and invoke causal analysis of a contextualized problem. Although this partial teacher-directed and student approach is focused on ill-structured problems, CBL does not necessarily ask students to independently generate a solution (Jonassen, 2011). Rather, CBL focuses more on providing a setting for learners to discuss a contextualized problem with the guidance of an instructor (Dabbagh & Dass, 2013; Williams, 1992). In a CBL approach, ill-structured cases serve as a context for students to analyze how and why the problem was resolved. Therefore, instructors use their discussions of the case to facilitate learners' contextualization of abstract content knowledge and support learners in understanding how professionals resolved the issue. However, students have fewer opportunities to actually engage in independent inquiry when compared with PBL or when a lecture is presented prior to problem-solving. To date, research suggested that CBL provides better clinical reasoning skills than a lecture-based approach for aspects including problem representation (Raurell-Torredà et al., 2015), conceptual knowledge (Dupuis & Persky, 2008; Tathe & Singh, 2014), motivation and communication (Yoo & Park, 2014), and collaborative problem-solving (Yoo & Park, 2015).

Although higher levels of student-directed learning may lead to gains in conceptual knowledge, problem-solving skills, and self-efficacy, theorists and practitioners must also account for other factors such as the nature of the discipline or learners' cognitive level. Currently, very few studies have attempted to directly compare the differences between these instructional strategies across cognitive and affective measures. In one study, Srinivasan and colleagues (2007) employed surveys to assess faculty and students' perception of PBL and CBL within a medical education setting. The study found that learners felt that PBL better supported self-directed learning, but the CBL approach was more directed and focused on knowledge application. Similarly, Seita and colleagues (2011) found that first-year medical students rated a CBL approach higher on motivation and perceived problem-solving when compared with PBL. However, few studies have been completed outside the medical education domain or looked at cognitive learning outcomes.

Research Questions

Conceptual knowledge, problem-solving (e.g., causal reasoning), and self-efficacy are all outcomes purported to increase from inquiry-based instruction. Given that PBL, lecture prior to problem-solving, and CBL each assume a different level of student and teacher-directed learning, uncertainty remains about which approach best supports cognitive and affective learning outcomes. Due to the prevalence of inquiry-based instruction in educational initiatives, additional research is needed to understand how to best facilitate problem-solving in the classroom. To answer this question, we first test the theoretical assumption that instructional methods requiring a higher level of student-directed learning and problem-solving will produce higher achievements in conceptual knowledge, causal reasoning skills, and self-efficacy. Given the research gaps discussed above, we identify the following research questions:

1. To what extent does the degree of directedness in problem-based learning (student-directed learning), lecture prior to problem-solving (partially student- and teacher-directed), and case-based learning (teacher-directed learning) differ in terms of helping students *attain conceptual knowledge*?
2. To what extent does the degree of directedness in problem-based learning (student-directed learning), lecture prior to problem-solving (partially student- and teacher-directed), and case-based learning (teacher-directed learning) differ in terms of developing *causal reasoning skills*?
3. To what extent does the degree of directedness in problem-based learning (student-directed learning), lecture prior to problem-solving (partially student- and teacher-directed), and case-based learning (teacher-directed learning) differ in terms of developing *perceptions of self-efficacy*?

Methodology

This section details the procedures employed for this experiment. Specifically, we define the conditions of PBL, lecture prior to problem-solving, and CBL and describe how each condition constructed a causal map to solve the ill-structured problem. We also discuss how we approached measurements of conceptual understanding, causal reasoning, and self-efficacy.

Participants

Participants consisted of 96 students enrolled in a class entitled "Sales Management." The class primarily enrolled junior-level marketing students at a large university located in the Midwestern region of the United States. All students were provided with the option to participate in the study and all signed the institutional review board (IRB) consent form.

Materials

Ill-structured Problem

Participants were asked to solve an ill-structured problem entitled "Nick's Dilemma." In this problem, learners are presented with a sales management hiring decision posed to Nick and his boss (Sheila). The participants read about how their employer, a medical device company, recently underwent significant turnover and suffered a great deal of market share loss. As the participants further read the problem, they were presented with two candidates: Lewis and Terry. The former possessed strong work experience in sales management and a high grade point average, which would reduce training costs. Although Lewis had intentionally omitted a driving under the influence arrest that had happened years ago, he offered to pay for any additional insurance when confronted. Alternatively, Terry had been with the company for over 10 years, but she worked as a customer service representative in the company's call center. Although loyal to the company, it was unclear if her experience would translate to a traveling sales representative role requiring skills such as client relationship building and proactive marketing. Finally, students were also given information about advertising in local media outlets if they desire to restart the search. Each decision has cause-effect implications for training costs, market share, employee growth, employee morale, and company culture.

Causal Reasoning Map

In the study, participants were asked to construct causal maps that depicted all possible viable solutions and outcomes as it pertained to "Nick's Dilemma". For instance, participants could depict the cause-effect relationships to determine what might happen if they opted to hire from within, hire the external candidate, or post a new advertisement. For the purposes of this study, causal maps are defined as a visual display that uses links and nodes to identify relationships between two different variables (Eseryel et al., 2013; Jonassen, 2011). In contrast to concept maps that show categories and clusters, the causal maps depict the directionality of the relationships between variables (see Figure 1). To avoid the use of different mapping software as a potential confounding factor in our study, the participants were instructed to use a single software to generate their causal maps (Coggle).

Because causal reasoning requires individuals to understand the problem space representation and determine the relationship of concepts, a causal reasoning map was used as a measure of problem-solving. This approach has also been used in prior studies as a valid measure of problem-solving (Eseryel et al., 2013; Ifenthaler, 2010; Olney et al. 2012). In line with expert-novice studies, theorists assert that causal maps can be assessed using a reference expert map (Giabbanelli et al. 2019; Ifenthaler, 2010). To construct the expert map, the first author facilitated a discussion with a subject matter expert (SME) to consider alternative pathways of the case and depict outcomes using Coggle. This SME map was generated initially by the instructor of record and validated by another practitioner with business experience. In total, the map was validated over three revision cycles and regularly compared with the learning objectives that students were asked to learn for that module.

Measurements

Pre- and Posttest

A pretest/posttest instrument used in previous studies (Tawfik & Jonassen, 2013) was chosen to measure the students' conceptual understanding about the sales management topics.

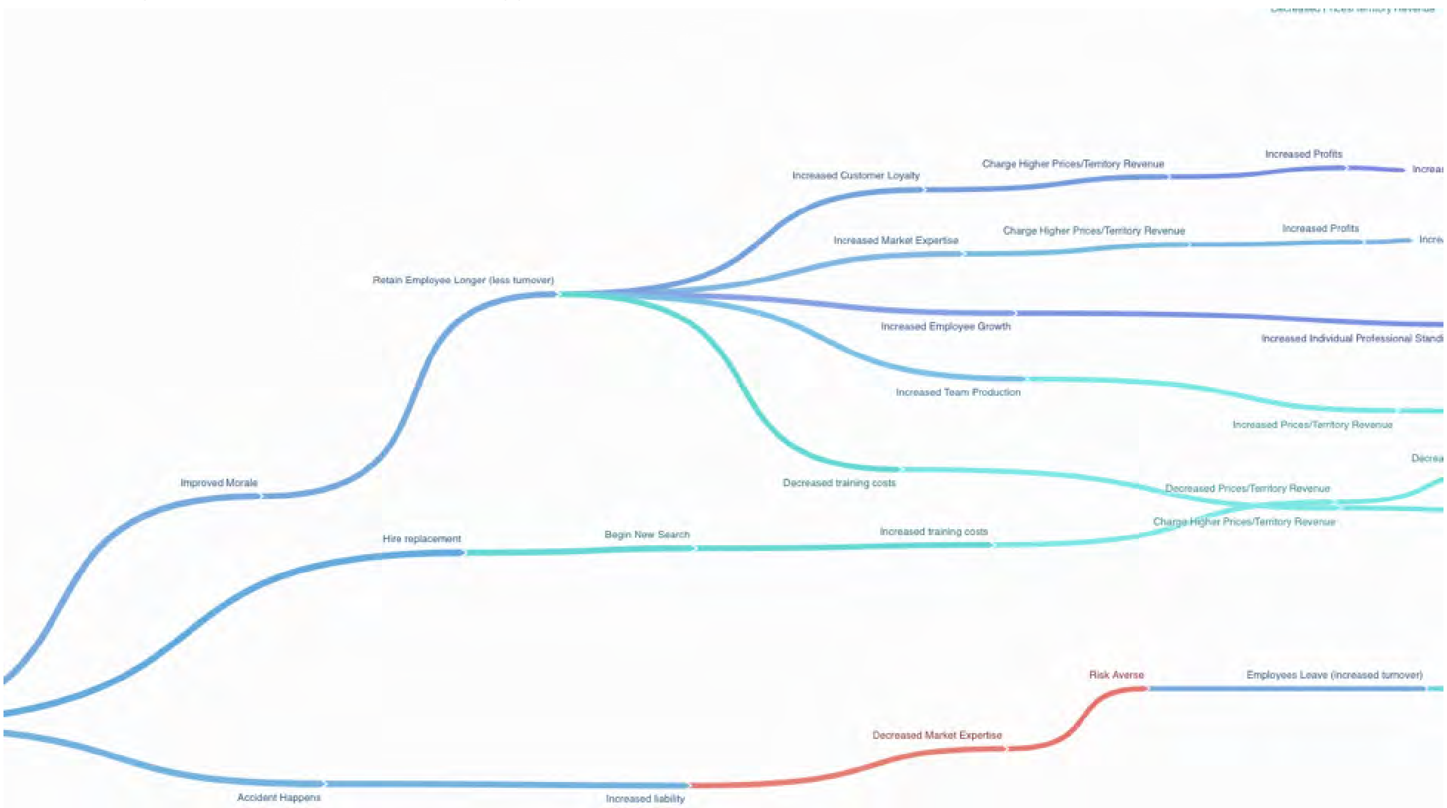

Figure 1. Referent Causal Reasoning Map

The pretest was given to (a) understand potential differences between groups and (b) serve as a baseline for improvement. The instrument contained 20 multiple choice questions which were mapped to objectives for the given modules.

Problem-Solving Inventory (PSI)

To answer the question about potential differences in self-efficacy, participants were assigned the problem-solving inventory (Heppner & Petersen, 1982). The goal of the PSI is to measure perceived self-efficacy in problem-solving (Heppner & Baker, 1997, p. 231). Although originating within the counseling domain, the instrument has since been employed in studies of classroom problem-solving, especially within the medical education domain (Woods, 2000; Woods et al., 1997; Yunus et al., 2006). In the original version, the PSI consists of 32 questions that measures items using a Likert scale. It is designed to load on three constructs: problem-solving self-efficacy, approach-avoidance style, and perceived personal control. Because we were primarily interested in problem-solving, we used problem-solving self-efficacy (a total of 11 items) and did not include the approach-avoidance style and perceived personal control, which both align more with the counseling domain. Given that the study took place within business education, the instrument was slightly adapted to the context of the class. Examples of adapted questions for the problem-solving portion of the PSI include: "Given enough time and effort, I believe I can solve most business problems that confront me" and " When I become aware of a business problem, one of the first things I do is to try to find out exactly what the problem is."

Causal Maps

As noted earlier, students were asked to construct a causal map using Coggle as part of the learning activity. The causal maps, representing the final product of student learning, were analyzed using several measures. The first measure consisted of the amount of concepts found in both the students' causal maps and the expert's map; that is, the number of correctly identified concepts. The maps were scored by the research assistant using a software that assessed causal reasoning charts (Giabbanelli et al., 2019).

To further measure students' causal reasoning, the number of correct causal connections was also measured. Connections were identified as correct if the students' concepts followed each other in the same way as they did in the expert's causal map. For instance, if the connections INCREASED EMPLOYEE MORALE → INCREASED EMPLOYEE RETENTION were found in both maps then the connections would be scored as a match. However, if the causal connections INCREASED EMPLOYEE RETENTION → INCREASED MARKET SHARE were found in the student map but were not connected in the expert map, they would not be scored as a correct connection.

Procedures

During the first week of the intervention, pretests (conceptual knowledge test, PSI) were administered to establish a baseline assessment. Prior to the problem-solving activities, the instructor assigned an unrelated causal reasoning activity to the class (Week 4 of the semester). In this activity, participants were asked to detail the potential job opportunities of a sales representative. This unrelated task was included to introduce the students to the causal reasoning software (Coggle) and thus remove unfamiliarity with the technology as a potential confound. Students were given one week to complete the activity (See Table 1).

In the week that followed (Week 5), student sections were randomly assigned to three different conditions based on their section: PBL (N=34), lecture-prior to problem-solving (N = 31), and CBL (N = 31). The instructor was the same individual for each of the 75-minute class sections. Prior to causal reasoning activities, two instruments were administered that served as a baseline. First, students were given a pretest to determine potential differences in prior conceptual understanding. Students were also given the PSI (Heppner & Petersen, 1982) to determine how the different inquiry-based instruction approaches might influence perceived self-efficacy.

In the PBL condition, participants were randomly assigned to groups (3-5 members) and asked to solve an ill-structured sales management problem ("Nick's Dilemma") for two weeks. Specifically, they were asked to conceive of as many viable solutions as possible and then create a causal map that connects concepts using a causal reasoning software (Coggle). Participants were allowed to discuss the problem in groups while the instructor would traverse around the class and discuss the relevant concepts with groups. In the lecture prior to problem-solving condition, participants were given a one-week lecture that described relevant concepts germane to the problem-space. In the following week, participants were asked to solve the ill-structured problem within their group tables. In the CBL condition, the instructor led a student discussion about how to solve the problem for two weeks. At the end of the task, participants in all conditions were asked to submit individual causal maps. To address potential bias, the instructor had a list of objectives to cover and made an effort to ensure each was covered.

In the final week (Week 7), learners were given a posttest and PSI survey to determine the influence of the instructional strategy.

Table 1. Experiment Conditions and Activities Timeline

Week	Problem-Based Learning (Student-Directed)	Lecture Prior to Problem-solving (Partial Student- and Teacher-Directed)	Case-Based Learning (Teacher-Directed)
4	Unrelated activity to familiarize with causal software (Coggle)	Unrelated activity to familiarize with causal software (Coggle)	Unrelated activity to familiarize with causal software (Coggle)
5	Administer conceptual pretest Administer problem-solving inventory	Administer conceptual pretest Administer problem-solving inventory	Administer conceptual pretest Administer problem-solving inventory
6	Participants complete Nick's Dilemma in groups using causal software (Coggle) Instructor facilitation with groups	Instructor-led lecture	Instructor-led discussion of Nick's Dilemma
7	Participants complete Nick's Dilemma using causal reasoning software (Coggle) Instructor facilitation	Participants complete Nick's Dilemma using causal reasoning software (Coggle) Instructor facilitation	Instructor-led discussion of Nick's Dilemma using causal reasoning software (Coggle)
8	Administer conceptual posttest Administer problem-solving inventory	Administer conceptual posttest Administer problem-solving inventory	Administer conceptual posttest Administer problem-solving inventory

Results

Conceptual Understanding of the Problem Space

The first research question sought to answer the degree to which directedness variations in the three conditions (PBL, lecture prior to problem-solving, and CBL) resulted in a significant difference in the participants' conceptual understanding of the subject. The pretest scores of the three conditions were as follows: CBL group (M = 11.86; SD = 2.51), lecture prior to problem-solving group (M = 12.18; SD = 2.57), and PBL group (M = 12.97; SD= 2.89). An ANOVA was performed on the students' pretest scores to ensure the equivalent level of prior knowledge on the subject among the three groups. No statistically significant differences were found among the three groups' performance from the pretest (df = 2; F = 1.44; p = .24).

After the treatment, the PBL group (M = 14.35; SD = 2.39) obtained the highest posttest scores, followed by the lecture prior to problem-solving group (M = 12.89; SD = 2.39), and the CBL group scored the lowest (M = 12.54; SD = 2.85). To test the difference among the three groups on their conceptual understanding, a one-way ANOVA test was performed on the posttest scores. A significant difference was found between the conditions (df = 2; F = 4.54; p = .013). A Tukey HSD post hoc test was consequently conducted to further identify where the differences resided. Results showed a statistically significant difference between the PBL and CBL conditions (p = .017) and no significant difference between PBL and lecture prior to problem-solving (p = .068). Also, no statistically significant differences were found between the CBL and lecture prior to problem-solving conditions (p = .859).

Causal Maps of the Problem Space

Our second research question was whether the different levels of directedness in these inquiry-based approaches affected the development of student problem-solving skills, namely causal reasoning skills. Rather than only use the total number of concepts in the students' causal maps as an indicator of learning, the students were assessed by the numbers of (a) correct concepts, (b) incorrect concepts, and (c) correct connectors among concepts identified.

In terms of the number of correct concepts identified by the students, the PBL group obtained the highest mean score (M = 8.71, SD = 3.06), followed by the lecture prior to problem-solving group (M = 8.18, SD = 3.57), and the CBL group scored the lowest (M = 7.73, SD = 3.45). Further analysis of the incorrect concepts yielded additional insight as to students' causal reasoning. Once again, the incorrect concepts are defined as the concepts that appeared in the students' causal maps, but not in the expert map. For this measurement, the PBL group included the highest number of incorrect concepts in their causal maps (M = 53.94, SD = 21.10), the lecture prior to problem-solving group followed (M = 39.36, SD = 25.12), and the CBL group scored the lowest (M = 35.23, SD = 19.25). Lastly, the number of the correct connectors on the students' causal maps (i.e., correctly describing the interrelationships among the concepts that explained the topic) was also examined. The PBL group remained as the highest performance group (M = 1.44, SD = 1.63), the CBL group came in next (M = .93, SD = 1.55), and the lecture prior to problem-solving group (M = .43, SD = .84) performed the lowest on this measurement.

A one-way MANOVA was carried out to test the differences among the three groups in terms of the students' performance on their causal reasoning skills. A significant difference was found in the three groups' mean scores in their causal maps (Wilk's λ = .809, F (6, 170) = 3.163, p = .006). Since a significance difference of the overall test was found, the univariate main effects were further examined. It revealed that significant univariate main effects for the three groups were obtained for incorrect concepts (F (2, 87) = 6.283, p =.003, partial eta square =.126) and connectors (F (2, 87) =3.882, p =.024 , partial eta square = .082). There was no significant difference for correct concept (p>.05).

Tukey HSD post hoc tests were performed to ascertain where the differences were found. The Tukey HSD showed that the significant differences occurred between the PBL group and the lecture prior to problem-solving group (p = .018) in their number of correctly identified connectors on their causal map. The PBL group significantly outperformed the other two groups in this measure. The Tukey HSD test further showed that the PBL group significantly included more incorrect concepts in their causal maps than did the CBL group (p = .003) and the lecture prior to problem-solving (p = .031). In other words, the PBL group was more likely to falsely identify concepts in their causal maps when compared with the lecture prior to problem-solving and CBL groups.

Problem-Solving Inventory (PSI)

The last research question of this study asked whether the level of directedness in inquiry-based instruction affected the participants' development of self-efficacy when solving the ill-structured problems. In the pretest, lecture prior to problem-solving obtained the highest mean score on the PSI (M=64.238, SD=6.48), PBL scored the lowest (M=59.76, SD=6.72), and CBL was in between (M=60.71, SD=5.90). After the treatments, the lecture prior to problem-solving group remained the highest level of self-efficacy among the three groups (M=64.90, SD=5.90), CBL group roughly maintained the same level (M=61.33, SD=7.28), and PBL continued to score the lowest in this measurement (M=61.03, SD=5.91).

An ANOVA test was performed to test the difference in the three groups' posttest PSI scores. The result showed that there was no significant difference among the three conditions (df=2, F=2.704, p=.073). However, a statistically significant difference was found in the students' pretest PSI scores among the three conditions (df=2, F=3.272, p=.043). Since there was a significant difference in the PSI pretest among the three groups, a Tukey HSD post hoc test was further performed. The result showed that the lecture prior to problem-solving group had a significantly higher level of self-efficacy in problem-solving than did the PBL group (p=.037) in PSI pretest. With the finding of a significant difference among the three groups' pretest scores, an ANCOVA was performed on the students' post PSI scores using pre PSI scores as a covariate. The result showed that there was still no significant difference among the three groups' post PSI scores after the students' pre PSI scores were taken into account. This finding was interesting because the significant difference between lecture prior to problem-solving and PBL groups in the pretest PSI scores dissolved in the posttest PSI scores. The PBL group's self-efficacy level rose to a level that was not significantly different from the lecture prior to problem-solving and CBL groups. Furthermore, a Pearson correlation coefficient test was performed to test whether there was a correlation between students' problem-solving self-efficacy level and conceptual knowledge posttest. No significant correlation between these two variables were detected (r = .114, p=.317).

Discussion

There has been a significant debate about the degree to which learners should be provided problem-solving experiences within the classroom (Hmelo-Silver et al., 2007; Kirschner et al., 2006; van Merriënboer, 2013). Indeed, it is theorized that a high degree of student-directed learning enables learners to actively identify their learning needs, create learning goals, and determine the resources needed to complete the task (Law et al., 2016). This impacts the degree to which they are able to synthesize their ideas from multiple sources and conceptualize the problem space (Jeong & Hmelo-Silver, 2010). Other data suggests different inquiry-based approaches impact students' learning outcomes in terms of affective measures, such as perceived self-efficacy (Srinivasan et al., 2007). In line with Barrows' (1986) taxonomy, a central point is how inquiry-based instruction should be balanced between the student and teacher during problem-solving (Loyens & Rikers, 2011). Thus, the overall goal of this study was to expand on prior research by exploring how the differing inquiry-based instructional approaches within PBL, lecture prior to problem-solving, and CBL impact learners' cognitive (conceptual understanding of the problem space, causal reasoning) and affective outcomes (self-efficacy).

One finding of this study was that PBL students outperformed the CBL group significantly in their conceptual understanding, as evidenced by posttest scores. Given that PBL did not include direct instruction from the teacher, the results gave a positive indicator to our first research question that a greater emphasis on student-directed learning could lead to a higher level of conceptual understanding. That said, this finding was somewhat surprising given that the CBL condition included a greater degree of teacher-led instruction—which one might argue is critical for novices' knowledge acquisition. This result may provide an indicator for supporting our hypothesis that PBL participants had greater degrees of self-direction during their learning that required them to acquire and simultaneously apply the domain knowledge they needed to solve the problem. This dual process of acquiring information and applying it towards a problem might have led to better retention and could have produced higher results on the conceptual posttest.

Student-directed learning and deep learning

An important element in inquiry-based instruction is a learner's ability to engage in causal reasoning within the problem space (Hmelo-Silver, 2013; Jonassen, 2011). As learners detail the causal relationships, they are required to articulate why the problem occurs and how it can be solved given the factors they identified as relevant (Eseryel et al., 2013). In contrast to other studies that explored causal maps holistically (Fitzgerald et al., 2011; Weinerth et al., 2014), this study extends prior research by exploring the following elements within the causal map: (a) correct concepts, (b) incorrect concepts, and (c) correct connectors among concepts. In this study, the PBL group performed the best among the three groups in identifying the correct concepts involved in the topic and the interrelationships among the concepts (connectors). Based on the greater number of concepts and number of connectors, one might hypothesize that PBL's more open-inquiry approach engendered additional opportunities to independently explore the issue and lead to a more connected understanding of the problem space.

This study is especially interesting in light of previous expert-novice studies. Whereas prior research examined how learners tend to identify surface elements of the problem space (Jacobson, 2001; Wolff et al., 2016), this study explored the ways in which learners actually connect ideas. With that focus, additional differences emerged in other measures of problem-solving; namely, the PBL group identified the highest number of incorrect concepts for the topic. This result provides a more nuanced view of problem-solving and leads to additional questions as to whether the high number of incorrect concepts identified in the PBL group's causal maps was a result of the low level of instructor guidance. The PBL group's observed trend of including high numbers of incorrect concepts in their causal maps coincides with other research that finds learners often join unrelated ideas during ill-structured problem-solving (Tawfik et al., 2018). This also provides evidence for Hmelo-Silver and colleagues' (2007) assertion that novices have a "tendency to erroneously reduce the complexity of a phenomenon" (p. 309). Although students in the PBL group were able to correctly connect ideas, we conjectured that they might have believed that a larger array of concepts identified during their information gathering was relevant and thus should be applied when solving the problem. Because the instructor in the PBL condition was not as prominent compared with the other conditions, the students may have been reticent to remove extraneous concepts encountered in their inquiry. As a consequence, the larger number of incorrect connections suggests their understanding may have been less refined when compared with the lecture prior to problem-solving and CBL conditions.

As hypothesized, the CBL group performed the lowest on the conceptual knowledge posttest and significantly lower than did the PBL group. Although some prior research has compared CBL and PBL on affective measures (Srinivasan et al., 2007), this study adds to the literature by simultaneously measuring cognitive and affective learning outcomes. As to their causal reasoning performance, the CBL group identified the least number of incorrect concepts in their causal map, which may have been due to the higher level of instructor guidance and modeling. In contrast to the PBL group, the instructor-driven format in the CBL group may have guided the learners to focus on the important variables and also eliminate the irrelevant variables during the case discussion. The class discussions may have allowed them opportunities to analyze when concepts were relevant to the problem space and quickly identify misconceptions. This classroom structure may have thus lead to fewer incorrect concepts during their causal reasoning. Interestingly, this scaffolding did not seem to transfer to their conceptual understanding, as evidenced by the fact they performed significantly lower than the PBL group on the posttest. That is, their high level of instructor support may have been beneficial when solving the problem; however, the lower emphasis on student-directed inquiry may have inhibited their ability to transfer their learning once the instructor support was removed. In the current study, the results may also suggest that learning gains attained in lower student-directed learning approaches are a more temporal outcome that does not transfer to additional activities.

The lack of initial content knowledge in the PBL group may have produced increased inquiry leading to deeper understanding in terms of conceptual understanding and causal reasoning. Once again, the lecture prior to problem-solving and CBL conditions had a high degree of instructor involvement as they constructed their problem space. Therefore, the students in these two conditions might have perceived their content knowledge as complete and thus perceived less need to further elaborate and refine the concepts during the problem-solving process. Conversely, one might presume that the PBL group perceived a greater need to explore the problem space because they did not have sufficient content knowledge prior to engaging the problem-solving tasks. With this result, we suggest that the level of student-directed learning could affect the level of processing and concept elaboration among the different groups, as demonstrated in the significantly different levels of conceptual understanding and causal reasoning.

The final research questions focused on determining potential differences between the PBL, lecture prior to problem-solving, and CBL conditions in terms of self-efficacy. Previous studies have explored the differences between CBL and PBL in terms of self-efficacy in the medical context and found that students scored higher when exposed to CBL (Seita, 2011; Srinivasn et al, 2007). This study, however, found no significant differences between the PBL, lecture prior to problem-solving, and CBL condition when evaluating student self-efficacy posttest scores. Thus, on the face value of the study results, a higher level of student-directed learning demand did not seem to promote students' self-efficacy during problem-solving. One explanation could be that self-efficacy is a rather fixed, personal self-perception that does not change over a short period of time or over the course of a single case. It may thus require sustained exposure to variations of inquiry-based instruction experiences before differences emerge. Further studies are needed to empirically validate this speculation.

Limitations and Future Studies

As noted earlier, the PBL condition in the current study had a greater number of overall concepts within the causal maps; however, they also had a significantly higher number of incorrect concepts identified when compared with lecture prior to problem-solving and CBL conditions. Theorists and practitioners might conclude the instructor's facilitation of the problem-solving process becomes critical to the students' refinement of their understanding of the problem space. In fact, the original version of PBL often prescribes a facilitator for a few groups (Barrows & Tamblyn, 1980). By introducing questions to guide examination of relevance, the instructor could have reduced the PBL group's number of incorrect concepts included in their causal maps. Once again, this study was conducted in a course where the problem-based instruction format was chosen by the instructor rather than a curriculum-wide or sustained implementation across multiple courses. In the PBL condition, the instructor had to go from one group to another to facilitate the students' learning and problem-solving. As a result, each group received scaffolding for a limited amount of time rather than the entire group session. The PBL condition's fragmentation of the class into smaller groups thus decreased the instructor's availability to each group for guidance and may have impacted the PBL group's performance in the problem-solving process. The results of the study lead to additional questions about whether the limited time during which the instructor could facilitate each group in a PBL module impacts students' problem-solving processes and learning. Indeed, it is possible the duration of the instructor's facilitation is a confounding variable. Future studies might compare conditions between students with a dedicated tutor during the entire group session versus a number of groups sharing an instructor's time. When compared with the other conditions that emphasized more teacher directedness, it is possible the PBL students may not have focused enough effort on removing concepts and repairing misconceptions.

While the results provide clarity on the appropriate degree of independent problem-solving to infuse in the classroom, there are multiple ways that researchers could build off of the current study. In the current study, the experiment was conducted over the course of five weeks. While PBL was more beneficial for conceptual understanding and certain measurements of causal reasoning, one might hypothesize that learners in the lecture prior to problem-solving or CBL condition might approach their instructor-led time differently with additional exposure to ill-structured problem-solving. It is possible that the differences between the conditions may have changed over time as learners became more familiar with the instructional format. Additional research from a longitudinal perspective might identify the degree to which these differences are sustained over time.

Another limitation was that the current study was taught by a single instructor within an undergraduate business class. Although efforts were made to control for the fidelity by having the same individual teach the class, it is possible that additional studies could more directly explore the role of the instructor and what content was explicitly addressed. For example, it would be helpful to assess the degree to which the instructor consistently administered the material in lecture form. As described in the Hmelo-Silver and Barrows (2006) case study, future studies could expand on the present research by focusing on the instructor interactions within PBL, lecture prior to problem-solving, and CBL conditions.

While our data suggested that a higher level of student-directed learning in PBL promotes better conceptual knowledge, it was not clear if this was consistent across all types of learners in terms of their levels of cognitive maturity and problem-solving ability. Indeed, it is very possible that the measurements (conceptual knowledge, causal reasoning skills, and self-efficacy) may vary depending on developmental levels. While this study extends the literature of inquiry-based instruction, it is conceivable that the results may have been different if the learners were selected from a K-12 setting or from a different domain. One might conclude that age groups respond differently to the degree of self-direction and learner autonomy present in PBL, lecture-prior to problem-solving, and CBL.

The current study uses three approaches to assess differences in inquiry-based approaches—conceptual knowledge, causal reasoning maps, and a self-efficacy survey. The performance of the students within the three conditions leads to additional questions about how to best evaluate students' learning process during problem-solving. The differential results may indicate that there were some processes (e.g., level of conceptual struggle or deep processing affected by the level of self-directed learning) that were not captured by just evaluating a single causal map. Therefore, future studies could examine the iterative problem-solving process. It is possible a series of causal maps that record different points of time during the problem space construction process may better provide us with a more complete reasoning process of students. Understanding critical factors such as the quality and depth of cognitive processing and the level of conceptual struggle would contribute to supporting learning outcomes.

Another study could also build upon the present research by looking at alternative forms of assessment. Although this study is unique in that it measured cognitive and affective measures to identify differences in approaches to inquiry-based instruction, other skills such as argumentation (Crowell & Kuhn, 2014; Nussbaum & Asterhan, 2016), quality of questions (Sullins & Graesser, 2014), and student discourse (Hmelo-Silver & Barrows, 2008) are possible measures of problem-solving. Additional forms of assessment would provide further insight about the appropriate balance between student- vs. teacher-directed learning.

Conclusion

Given that PBL, lecture prior to problem-solving, and CBL often espouse cases to catalyze ill-structured problem-solving, these inquiry-based approaches may be inadvertently presented as equal in their learning outcomes (Loyens & Rikers, 2011; Walker & Leary, 2009). According to Barrows (1986), a continuum exists in regards to the degree of student- or teacher-directed learning and may produce varying levels of conceptual knowledge, problem-solving skills, and self-efficacy. Therefore, the conflation among these three inquiry-based approaches in the literature may lead to errors in our ability to synthesize and understand the true impact of PBL (Lazonder & Harmsen, 2016; Walker & Leary, 2009). This could then impact which solutions educators seek out to implement in classroom contexts.

Based on the results, we assert that the higher level of student directedness represented by the PBL approach might promote students' deep processing at a conceptual level. Specifically, the PBL students' conceptual understanding of topics was much more robust compared to the instructional approaches that employed medium levels (represented by the lecture prior to problem-solving approach) and low levels (represented by the CBL approach) of student-directed learning. While the students in the PBL condition outperformed their counterparts on conceptual knowledge, overall concepts, and correct connections, the finding that PBL students identified more incorrect concepts merits further studies. This may lead to a shift in discussion about how to grow students' conceptualization of the problem space and lead to additional research about strategies to refine understanding.

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