Applying Case-based Reasoning Theory to Support Problem-based Learning

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Abstract: Research has shown that learners have difficulty as they transition to ill-structured problems tasks. One way for educators to facilitate this transition is by applying case-based reasoning (CBR) theory in the form of case library learning environments. However, the research about how to best implement CBR theory remains limited. This is surprising given the importance of cases within goal-based scenarios, anchored instruction, problem-based learning, and cognitive flexibility theory. As such, further research of this educational technology will help ensure the application of these learning environments establish a foundation for effective higher order learning and problem-solving expertise. The current study evaluated three conditions (lecture, case library used in a collaborative context; case library used on an individual basis) on a problem-solving task. Results found the CBR collaboration group outperformed the other conditions on a posttest designed for problem-solving. Implications for implementation for instructional design are also discussed.

Keywords: case-based reasoning; case libraries; collaborative learning; problem-solving

Introduction

Modern cognitive scientists have noted the importance of ill-structured problem-solving to engender higher order learning skills such as causal reasoning, argumentation, and evaluation (Hmelo-Silver, 2013; Jonassen, 2011). While some have posited that problem-based learning (PBL) is an important instructional strategy, the research is somewhat mixed as to its efficacy (Leary & Walker, 2009). Some have further argued that implementation and scaffolds are a key factor that requires further examination in the PBL literature (Dabbagh & Dass, 2013; Hung, 2011).

Case-based reasoning (CBR) theory suggests that as knowledge and expertise increase, practitioners are able to assess the current problem, find previous cases relevant to the current problem, leverage that case to inform a solution, assess the potential solution, and update internal memory as one learns from the experience (Aamodt & Plaza, 1996). As such, one such way to support PBL is by the utilization of case library learning environments that include stories of practitioners' prob-

lem-solving experiences. However, very little empirical research currently exists as to the best means to support higher order learning through case libraries. Some might argue that individual analysis on these narratives might best support learning because learners are able to reflect on the case. Alternatively, others might argue that a collaborative approach would afford collective meaning-making as learners evaluate the case. If CBR might be used as a strategy to engender problem-solving competencies, further research is required to ascertain how to best apply case-libraries learning environments and its role in PBL (Jonassen, 2011).

Problem Solving

As learners move from the role of student to practitioner, they are initiated within a community where s/he is expected to perform (Wenger & Snyder, 2000; Wenger, 2000). In contrast to the classroom experience, practitioners are expected to perform in often ill-structured problem-solving contexts where no one "right" answer is verifiable. As such, the ability to engage in causal reasoning and argumentation to justify a

solution within a community of practice during problem-solving are essential skills of everyday practitioners (Henning, 2004; Jonassen & Kim, 2010; Kuhn & Udell, 2007). However, previous classroom approaches of learning have emphasized the didactic model, which requires the learner to merely become recipients of information. A fundamental limitation of the didactic instruction model is that content is often conveyed in a decontextualized manner. This mode of instruction often falters because this approach emphasizes conceptual recall or recognition rather than problem-solving (Brown, Collins, & Duguid, 1989; Hung, Jonassen, & Liu, 2008; Lave & Wenger, 1991). Specifically, the learner may be unclear how to extrapolate, combine, and employ concepts to solve authentic problems.

Brown et al. (1989) suggested that since knowledge is situated within authentic practice, instruction should be conducted in a similar manner. The authors further argued "students need much more than abstract concepts and self-contained examples. They need to be exposed to the domain's conceptual tools of authentic activity" (p. 34). Modern cognitive scientist have suggested that knowledge obtained through authentic activity is learned better and is therefore more applied to problem-solving compared with knowledge obtained through passive observation (Collins, Brown, & Newman, 1989; Jonassen, 2011; Schank, 1999). Schank (1993) further maintained a problem-solving emphasis on pedagogy engenders overall comprehension, retention, recognition of appropriate condition, and transfer.

Problem-based learning (PBL) has emerged as an important instructional strategy to address these issues. In contrast to the traditional classroom model, PBL prescribes the following (Barrows, 1996):

- Student-centered learning

- Self-directed learning

- Collaborative learning in small groups

- Teacher serves as facilitator

- Problem-serves as the catalyst for learning

While this instructional strategy began in the medical field, it has since seen increased emphasis in other domains such as education and business (Hung et al., 2008). To date, research has shown learning gains using PBL in causal reasoning (Jonassen & Ionas, 2008), argumentation (Andriessen, Baker, & Suthers, 2003; Kuhn & Udell, 2007), and knowledge construction (Riedel, Fitzgerald, Leven, & Toenshoff, 2003).

Despite the positive results, some have argued that PBL is counterintuitive to learning because the strategy taxes cognitive load (Kirschner, Sweller, & Clark, 2006). Henry et al. (2011) found that first-year PBL students had difficulty with issues such as collaboration in groups, role of facilitator, and ambiguity about what resources to employ. Similarly, recent meta-analyses of PBL have argued that its effectiveness is often impacted by how PBL is implemented (Leary & Walker, 2009). In a review of the research, Hung (2011) identified the following as barriers to learning in PBL: beginning the problem-solving process; information searching; application of scientific reasoning; and evaluation of solution. The information seeking process in particular is an aspect that causes frustration and requires significant time investment as individuals navigate through the ill-structured nature of problem-solving. For instance, Authors (2012) found that students cited the information searching, variable identification, and evaluation of resources as barriers as engineering students engaged in a PBL course for the first time. Similarly, Laxman (2010) found that students cited difficulties in variable identification and information searches during an ill-structured problem-solving task. Based on this research, we argue the information seeking process requires further evaluation as students transition to PBL.

Case Based Reasoning

One potential way to overcome these challenges is through an application of case-based reasoning (CBR) theory and case library learning environments. The CBR model of cognition is based upon a form of analogical reasoning which suggests individuals encode previous experience in memory in the form of contextualized cases (Kolodner, Owensby, & Guzdial, 2004; Schank, 1999). In practice, solving problems is frequently supported by recalling prior experiences of similar situations (Jonassen, 2010). These experiences, stored in the form of cases, represent the interpretations of previous problem-solving experiences and the subsequent lessons learned. As knowledge and expertise increases, practitioners rely more on reusing previous cases that are relevant to the current problem rather than linear problem-solving processes, a process known as case-based reasoning (CBR) (Kolodner, 1993). According to CBR theory, an encountered problem (the new case) prompts the individual to retrieve cases from memory, reuse the old case (i.e. interpret the new in terms of the old), which suggests a solution (Aamodt & Plaza; 1996; see Figure 1). When the effectiveness of the new solution is confirmed, the knowledge is then stored in memory as a case for later use. Embedded within each case are a series of indices, which aide in memory retrieval. As such, learning is thus largely comprised of accumulated problem-solving experiences (Kolodner, Owensby, & Guzdial, 2004; Schank, 1999). Over time, these experiences are often stored in a 'case library' within memory from which the practitioner can reference to solve novel problems (Jonassen, 2010;
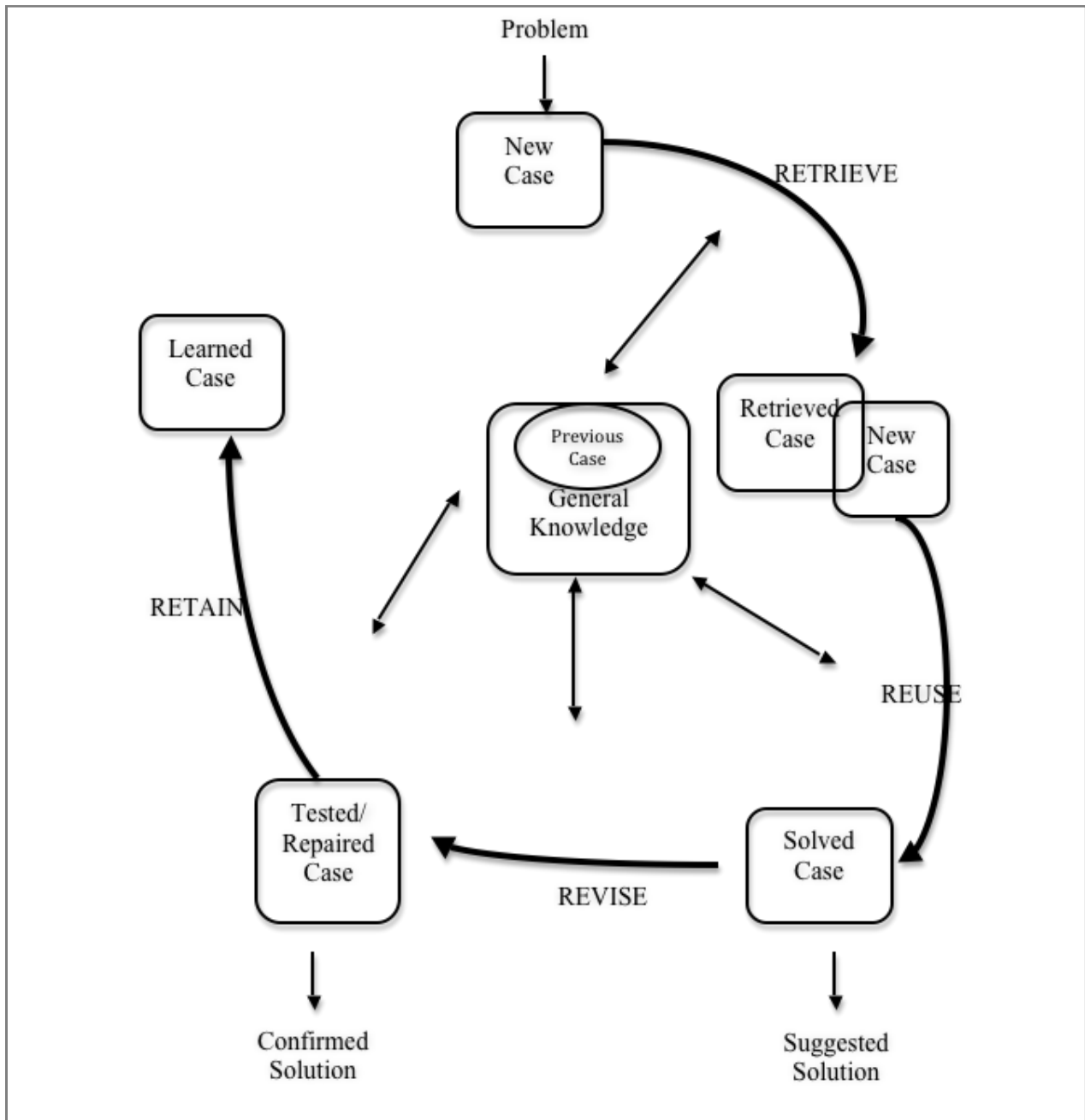
Figure 1. CBR Cycle, adapted from Aamodt & Plaza, 1996.

Schank, 1999).

CBR posits that remembering relevant cases situated within an authentic context better facilitates knowledge acquisition and subsequent analogical transfer (Kolodner, Cox, & Gonzalez-Calero, 2005; Kolodner et al., 2004). In communities of practice, experts generate scripts as problem-solving experiences throughout their careers (Schank & Abelson, 1977). For example, physicians generate increasingly comprehensive knowledge based on previous diagnostic cases, often referred to as illness scripts (Jonassen, 2011). Problem-solving is thus is based on a kind of pattern recognition constructed from previous cases (Schmidt

& Boshuizen, 1993; Schmidt & Rikers, 2007). This form of analogical reasoning is important to problem-solving because it allows individuals to apply concepts learned in one context to as an aide in solving similar problems (Gick & Holyoak, 1983). Experts are often able to identify patterns and engage in high-level reasoning with additional expertise (X. Wang et al., 2012) as case libraries and indices subsequently grow within memory.

Case Library Learning Environments

Kolodner et al. (2004) argued novices have the following problems during transfer when problem-

solving within a new domain: poor encoding of previous experiences that impedes appropriate retrieval; inadequate mapping between concepts; and difficulty employing experiences when they do not have appropriate recall experiences. To overcome these challenges, one option is to provide a database of cases that consist of various practitioner experiences for learners to reference. Case libraries learning environments are databases of practitioner stories that are made available to learners as advice during a problem-solving task. In doing so, the case library learning environment is analogous to the case library found within the memory of practitioners. Reflection upon the narratives of practitioners serves as a proxy for the experience the novices do not yet possess (Hernandez-Serrano et al., 2002). Case libraries learning environments also play a critical role in learning by providing experiential knowledge of practitioners and expert modeling to novices who lack the experience (Kolodner et al., 2004). Ideally, the learner is able to avoid a linear view of problem-solving as the read about the diversity of challenges experienced by multiple practitioners. As multiple stories are encountered within the case library learning environment by the learner, the stories become indexed in the learner's episodic memory (Kolodner et al., 2005; Schank, Berman, & Macpherson, 1999).

Because cases libraries memory structures are largely built upon narratives of how experienced practitioners have solved similar problems, case libraries learning environments augment the previous experiences of novices who have yet to encounter critical experiences by modeling problem-solving when a learner is uncertain about how to solve a problem (Jonassen & Hung, 2006). As multiple stories are encountered within the library, the narratives supplement learner's episodic memory and serves as a just-in-time learning resource to solve the problem (Kolodner et al., 2005; Schank et al., 1999). Case library learning environments may also help alleviate some of the information seeking challenges cited in PBL (Henry et al., 2012; Hung, 2011), while still allowing for self-directed learning and analogical transfer as students garner meaning from the cases.

Case library leverages the power of story-telling shared with a community of practice to convey these experiences and the associated problem-solving competencies. In memory, Schank (1995, 1999) has argued that understanding of a story requires an individual to engage in index extraction as s/he finds similar stories. Stories are therefore essential to the CBR model of cognition and case libraries because these narratives include numerous indices within a story such as locations, beliefs, attitudes, decisions, and conclusions (Schank, 1999). As such, story-based memories are a way of "preserving the connectivity of events that would otherwise be dissociated over time" (p. 95) within a commu-

nity of practice. In relation to problem-solving, sharing of stories helps to activate and connect other relevant problem-solving stories that aide in analogical transfer. Furthermore, stories are able to relay tacit knowledge that is not easily expressed within traditional knowledge artifacts (Sanchez, 2011; Sole & Wilson, 1999). Workplace research has shown that communities of practice collaboratively employ stories as a way to share knowledge amongst its members (Henning, 2004; Hernandez-Serrano & Stefanou, 2009). Story-telling thus serves the primary medium that provides increasingly concrete and cohesive representations of interrelated, complex concepts and passes along cultural principles to peripheral members within communities of practice (Wang, Jonassen, Strobel, & Cernusca, 2003; Wenger & Snyder, 2000).

Despite the potential benefits, the efficacy of case libraries to support learning is still largely lacking in empirical research (Jonassen, 2011). However, some research has sought to investigate the impact of case library learning environments to support PBL. In one study, Hernandez-Serrano and Jonassen (2003) compared three groups that accessed different resources during a PBL activity: case library learning environment, fact sheets, and textbook. The researchers found that students who accessed a case library learning environments where able to outperform a control group on a multiple-choice test that assessed problem-solving skills (prediction, inferences, explanations). In another study, Authors (2013) found that those students that individually accessed a case library learning environment that detailed failure stories outperformed students that accessed stories of successful problem-solving. The authors argued that the failure stories helped to make the causality more overt and thus more memorable for future problem-solving. Both studies suggest that the resources students employ supports students learning as they problem-solve in PBL.

Research Questions

Despite the promising results of the case libraries, further research is needed to understand how to best apply case library learning environments. In the previous study (Authors, 2013), students were asked to individually view the case library learning environments. However, advocates of PBL have argued collaboration and group work is a central component to the PBL model of instruction (Barrows, 1996; Hmelo-Silver, 2013). The Authors (2013) study only compared two different versions of case library learning environments (success, failure), but did not address whether a PBL approach using these supports would outperform a lecture-based approach. To address these gaps in the research, we posit the following research questions:

1. To what extent does learning performance differ on a

problem-solving assessment if the participant engages in a lecture or case based learning environment?

2. To what extent does learning performance differ if the participant employs case based learning environment on an individual or collaborative basis?

Methodology

Participants

Participants were drawn from undergraduate business students enrolling in a Sales Management course, an upper-division course offered in the College of Business at a Midwestern university located in the United States. A total of 76 students were enrolled in the course across three sections (Male = 39, Female = 37). This particular course generally enrolled junior level marketing students. All participants voluntarily elected to participate in the study.

Procedure

Rather than randomly assign individuals to the different treatments, participants were assigned the case libraries based on their course section (intact groups). Participants were assigned by section because participants often employed group work in the sales management class. The course sections were assigned to different case libraries using a Microsoft Excel randomization macro. In the eighth week of the semester, participants were given a pretest to establish any difference in prior knowledge between the groups. Upon completion of the pretest, participants in two groups (individual, collaborative) were asked to navigate to a web-based learning environment to access an ill-structured, decision-making problem to solve. The task required participants to construct an argument as to why they would hire a particular individual. The control group proceeded as normal using a lecture-based approach. In the ninth week, all participants were given a posttest to assess differences in learning.

Materials

The problem to solve embedded in the learning environment presented the participants (individuals and collaborative conditions) with an authentic ill-structured hiring problem the SME had encountered (see Figure 2). The decision-making problem details "Nick" as he tries fill a traveling sales position at a large corporation. "Lewis" is a potential candidate that has strong character references and relatable skills, but Nick discovers Lewis failed to disclose a driving under the influence citation from years ago. This presents a problem because it suggests Lewis still has character issues and increases insurance costs for the company. However, the training costs for candidates without experience is substantial and the character references imply the indis-

cretions were aberrant. Based on these factors, it is unclear whether to hire this individual or revisit the job search.

While solving the task, students were prompted to access five cases that detailed practitioners failed problem-solving experiences (see Appendix A for example) . In general, the cases were designed using the following framework: setting (e.g., steel mill, entrepreneurial endeavor), general problem description (e.g., changing jobs within industries, hiring qualified workers), assumptions (e.g., different roles require different skillsets), constraints (e.g., market pressure, glass ceiling), social issues (social fit, employee morale), overarching lesson (e.g., hiring qualified workforce, job placement alignment), and outcome (e.g., loss of customers, increased turnover). This framework helped to maintain instructional consistency across each of the narratives.

Figure 2. The Learning Environment

Table 1. *SME Case Library Interview Protocol*

Stories Protocol – Failure	Goal
1. Please explain to me a failed story in regards to a hiring and selection strategy?	Problem-situation-topic indexes
2. What were the relevant concepts (indices) embedded within story you just described?	Problem-situation-topic indexes
3. What were the goals-subgoals-intentions to the context?	Problem-situation-topic indexes
4. What were the constraints of the context described?	Problem-situation-topic indexes
5. What solution was developed to solve the problem?	Appropriate solution indexes
6. What was the justification for the proposed solution?	Appropriate solution indexes
7. What acceptable, alternative solutions were suggested but not chosen?	Appropriate solution indexes
8. What unacceptable, alternative solutions were not chosen?	Appropriate solution indexes
9. Why was this solution unacceptable?	Appropriate outcome indexes
10. If failure, what repair strategies could have been employed?	Appropriate outcome indexes

To construct the case library, the researcher interviewed a subject matter expert (SME) who had over 20 years of experience in various areas of business. The researcher interviewed the SME using the semi-structured protocol prescribed by Jonassen and Hernandez-Serrano (2002) (see Table 1). After the researcher translated the interview into the narratives, the SME reviewed the cases for accuracy.

Instruments

A 25-item, five-option multiple choicetest was administered as the primary assessment method for the pretest and posttest. The assessment consisted of the learning objectives for the module. At the beginning, the assessment was used as a pretest to identify any differences in domain knowledge between the treatment groups. Towards the end of the experiment, the assessment was used to ascertain learning gains.

Various measures were taken to ensure the validity and reliability of the tests. In terms of validity, the test was created by the SME and reviewed by three graduate assistants. Each item was assessed in two areas: learning objective and problem-solving. In terms of the former, the SME created the test and cross-checked it with the learning objectives. When SME and researcher identified questions that were not related, the question was omitted from the test or revised to accurately reflect the sales management concept.

After the SME created the test questions, the SME and researcher met once again to determine if the assessment were posed as problem-solving questions. At this stage, we created the assessment in accordance with the methods prescribed by Jonassen (2011). That is, questions were contextualized and answers were largely focused on causal reasoning, inferences, predictions, and explanations. Upon completion, the test was given to three graduate students as a pilot of the test.

Results

The experiment analyzed differences between the three groups using an analysis of variance (ANOVA) test. Prior to the analysis, a Shapiro Wilk test was conducted to identify potential problems with normality. Results of the test allowed the analysis to proceed with the assumption of normal distributions between groups (Lecture $p = .455$; CBR Collaborative $p = .738$; CBR individual $p = .273$). Upon completion, an ANOVA test was completed for the pretest to ascertain potential differences in prior knowledge. However, no differences were found between the pretest scores (DF = 2, 74; F = 1.186; $p = .311$). As such, the experiment proceeded assuming equal prior knowledge among groups.

The results of the posttest found the CBR-collaborative (60.00) outperformed the lecture (51.08) and CBR-individual (51.80) treatment groups (see Table 2). To empirically identify significant differences, we once again conducted a one-way ANOVA for the posttest scores. The analysis revealed differences between the groups (DF = 2; F = 2.35; $p = .016$). Based on these results, a post-hoc Scheffe's test was conducted. The more conservative Scheffe's test was selected over the Tukey's because of the unequal sample sizes. Results of the post hoc tests identified significant differences between the CBR collaborative and lecture groups ($p = .03$), but not between the individual groups (see Table 3).

Table 2. *Pretest/Posttest Mean Differences in Treatments*

	Pretest			Posttest	
	N	Mean	StDV	Mean	STDV
Lecture	26	49.54	10.68	51.08	8.86
CBR-Collaborative	31	53.68	12.08	60.00	16.69
CBR-Individual	20	50.00	9.75	51.80	8.65

Table 3. *Pretest/Posttest Mean Differences in Treatments*

		Mean Difference	StDV	Sig.
CBR-Individual	CBR-Collaborative	-8.20	3.61	0.08
	Lecture	0.72	3.75	0.98
CBR-Collaborative	CBR-Individual	8.20	3.61	0.08
	Lecture	8.92*	3.35	0.03
Lecture	CBR-Individual	-0.72	3.75	0.98
	CBR Collaborative	-8.92*	3.35	0.03

*. The mean difference is significant at the 0.05 level.

Discussion

The current study had two primary goals. First, to ascertain if case library learning environments are a better means of supporting problem-solving when compared with the lecture-based model. Second, to determine if an individual or collaborative application of case-library learning environments was a better means of supporting PBL. In order to assess problem-solving, participants were given a test that assessed participants' ability to engage in causal reasoning, inferences, predictions, and explanations. The results of the data analysis suggest that the participants that learned the concepts in the lecture format and individual case library treatment did not show significant differences on posttest scores when compared to the collaborative case library treatment. That is, those that accessed the case library in a collaborative context outperformed the other treatments on a problem-solving posttest.

There may be multiple reasons for these results. Schank (1999) notes that failure cases pose a mental discomfort that naturally affords an explanation by the learner. In the individual treatment, it is possible the interpretations of the failure cases were somewhat ambiguous. That is, learners were still unclear about how to garner meaning from the cases and its implications to solving the presented ill-structured problem. As such, the indices generated within memory were still circumspect in the mind of the participant as they tried to problem-solve in new contexts. This may have caused limited indices for the retain aspect of the CBR cycle, which later impeded the retrieval aspects of CBR during the problem-solving task.

This study adds to the CBR research by suggesting that a collaborative approach might best support student learning as they employ case library learning environments for PBL. It is possible that the collaborative group collectively assigned meaning and interpretations when reading the narratives embedded in the case library. In contrast to the lecture or individual approach, collaboration may have allowed individuals to articulate their interpretations of the case to peers; justify their position; provide explanations (Ge, Planes, & Er, 2010). In doing so, the indices generated during the CBR process were challenged and negotiated as the group problem-solved. This may have also lead to erroneous indices to be revised during the collaboration process. These results also coincide with the PBL model, which suggests that collaboration is a key element during the problem-solving process. Moreover, the model of learning whereby individuals negotiate meaning about how to apply cases to new problems is also representative of the communities of practice model whereby individuals negotiate what cases to apply in order to solve new problems (Hernandez-Serrano & Stefanou, 2009).

The results also build upon the previous studies of CBR and its application to PBL. In the current study those in the case library learning environments were able to outperform those in the didactic model, similar to the Hernandez-Serrano and Jonassen (2003) study. Dabbagh and Dass (2013) argued that cases can be employed to support problem-solving instruction in various ways. Similarly, others have argued that exposure to authentic learning experiences in the form of cases may be one way to facilitate problem-solving (Boshuizen, Wiel, & Schmidt, 2012; Hernandez-Serrano & Jonassen, 2003). However, little empirical validation exists as to the learning impact based on how cases are implemented and employed during problem-solving. This is surprising given the importance of cases within goal-based scenarios (Schank et al., 1993), anchored instruction (Cognition and Technology Group, 1991), and cognitive flexibility theory (Feltovich, Spiro, Coulson, & Feltovich, 1996; Spiro, Coulson, Feltovich, & Anderson, 1998). Each of these instructional strategies employ cases to convey the ill-structured nature of problem-solving and authentic problem solving, yet little is known how to strategically utilize the cases to optimize PBL. The results of the study suggest case libraries may be one way to provide expert guidance using a narrative approach that describes how practitioners solve problems. Case libraries also scaffolds the students as expert problem-solving related to problem analysis, justification, and solution generation become more overt to the learner in a contextualized narrative. Moreover, this approach may help to ease the transition of problem-solving and information searching previously supported in other PBL implementations (Hung, 2011; Vardi & Ciccarelli, 2008).

Limitations and Future Studies

While the results of the study suggest provide further empirical evidence about the efficacy of case libraries, future studies could build upon the limitations of the study. In the described study, two case library treatments (individual, collaborative) were compared with a lecture-based approach to a sales management PBL activity. However, it is somewhat unclear if case libraries unknowingly limit the creativity of students as they problem-solve. That is, students did not look for variables and factors beyond what was found in the case library. Because case libraries are dependent upon the experiences of the practitioner, it is possible that the solutions presented in the cases are limited to the his/her experience. It is also possible that an approach that encourages students to search for their own solutions outside the case library or a different information repository would identify solutions not present in the cases.

Another interesting study could investigate whether other forms of assessment would the results presented in the study. The current study asked students

to complete a posttest designed for problem-solving. However, the field of PBL would benefit from other problem-solving tasks such as argumentation essays or concept mapping to identify further differences in learning. Because these are different cognitive activities, it is possible individual or collaborative case library approach would have yielded different results and provided further insight into the case library application to PBL.

It is also unclear if the results would have been different if various scaffolds were embedded throughout the activity to help the reader reflect upon the case. Other researchers have noted the importance of scaffolds to support PBL for collaboration, argumentation, self-directed learning, and meaning making (Ge et al., 2010; Jeong & Lee, 2008). It is possible that question prompts would have caused the individual case library treatment to generate the same meaning in a similar fashion to the collaborative group. This study could build upon this research and provide further insight about how to the best means of supporting PBL and higher order learning.

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