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Enhancing Students' Higher Order Thinking Skills Through Computer-Based Scaffolding in Problem-Based Learning

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ENHANCING STUDENTS' HIGHER ORDER THINKING SKILLS THROUGH

COMPUTER-BASED SCAFFOLDING IN PROBLEM-BASED LEARNING

By

Nam Ju Kim

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ABSTRACT

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This multiple paper dissertation addressed several issues in Problem-based learning (PBL) through conceptual analysis, meta-analysis, and empirical research. PBL is characterized by ill-structured tasks, self-directed learning process, and a combination of individual and cooperative learning activities. Students who lack content knowledge and problem-solving skills may struggle to address associated tasks that are beyond their current ability levels in PBL. This dissertation addressed a) scaffolding characteristics (i.e., scaffolding types, delivery method, customization) and their effects on students' perception of optimal challenge in PBL, b) the possibility of virtual learning environments for PBL, and c) the importance of information literacy for successful PBL learning. Specifically, this dissertation demonstrated the effectiveness of scaffolding customization (i.e., fading, adding, and fading/adding) to enhance students' self-directed learning in PBL. Moreover, the effectiveness of scaffolding was greatest when scaffolding customization is self-selected than based on fixed-time interval and their performance. This suggests that it might be important for students to take responsibility for their learning in PBL and individualized and just-in-time scaffolding can be one of the solutions to address K-12 students' difficulties in improving problem-solving skills and adjusting to PBL.

(271 pages)

PUBLIC ABSTRACT

Enhancing Students' Higher Order Thinking Skills through Computer-based Scaffolding in Problem-based Learning

Nam Ju Kim

The purpose of this multiple-paper dissertation is to identify students' several difficulties occurring in Problem-based learning and to address these issues by suggesting the design of computer-based scaffolding. In addition, the effectiveness of suggested design was confirmed through meta-analysis and the empirical research. Learner-centered Scaffolding Systems (LSS) is presented to improve students' perception of optimal challenge by addressing students' learning issues in PBL. LSS enhances students' experience in autonomy and competence by providing multiple types, modalities, and customization of scaffolding in accordance with student' different needs and difficulties in PBL. Bayesian meta-analysis for identifying the effects of suggested LSS indicated that computer-based scaffolding significantly impacted ($g = 0.385$) cognitive outcomes in PBL for STEM education. In addition, the results showed the effects of each sub-category under scaffolding characteristics used in STEM education. Based on the research from conceptual and meta-analysis papers, the empirical research investigated the effect of two types of computer-based scaffolding on high school students' information literacy and argumentation skills in PBL with a scientific task. The several results in this dissertation indicated that individualized and just-in-time scaffolding can enhance student confidence and problem-solving skills to take on the ill-structured nature of PBL.

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Finally, I want to dedicate this dissertation to my family who is the most important thing in my life. I deeply thank my parents and parents-in-law in South Korea for their unfailing emotional support and unconditional trust. For all the things my hands have hold the best by far is my lovely baby, Ayden. And my dear wife who had to give up a lot of things for me. Her love and encouragement led me to where I am today. I will try harder to become your proud husband and no matter what happens, I will always love you, Dayun.

Nam Ju Kim

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CHAPTER I

INTRODUCTION OF MULTIPLE PAPER DISSERTATION

According to the Program for International Student Assessment (PISA, 2014), 15-year-old U.S. students' average score in terms of mathematics and science literacy/interest was lower than the OECD average although the amount of instructional time that U.S. students spend in mathematics and science instruction is much higher. This low performance has been consistent over the past few decades and contributes to a decline in the number of US students interested in science and engineering (National Academy of Engineering, 2005; National Science Board, 2006; Sanders, Kwon, Park, & Lee, 2011). To remedy these discouraging results, U.S. educators and policymakers have tried to reform K-12 education by changing the types of problems with which students are engaging (i.e., from decontextualized problem sets to authentic problem sets) without addressing the widespread use of teacher-centered approaches to instruction (van Driel, Beijaard, & Verloop, 2001; Watters, & Christensen, 2013). Such superficial changes have not contributed to a fundamental shift in student engagement and learning performance in Science and Mathematics (Boone, Townsend, & Staver, 2011). STEM education, as an alternative, is defined as an integrated curriculum of Science, Technology, Engineering, and Mathematics, which not only focuses on student engagement with authentic problem solving but also includes a fundamental shift from teacher-centered instruction to learner-centered instruction (International Technology Education Association, 2000). Learner-centered instruction in STEM allows students to assume responsibility for their own learning (Harpe & Phipps, 2008; Albon & Hubball, 2004) and to find their own methods to construct knowledge (Ebert-May et al., 2015). It leads to the improvement of students' interest, motivation and engagement toward science and mathematics as well as the learning performance (Sanders, 2009; Wang, 2013).

The various problem-centered instructional models (e.g., problem-based learning, inquiry-based learning, case-based learning, project-based learning and design-based learning) have been found to be effective approaches for STEM education. Especially, problem-based learning (PBL) aims to improve students' content knowledge and problem-solving skills through engagement with authentic and ill-structured problems, which have no single answer (Hmelo-Silver, 2004; Kolodner et al., 2003; Thistlethwaite et al., 2012). PBL requires students to (a) search for, analyze, and evaluate information for problem-solving, (b) develop the claims, and (c) create an argument to support the claims (Christe, Shah, Bhatt, Powell, & Kontsos, 2015). Many studies have demonstrated the effectiveness of PBL in enhancing students' content knowledge and higher-order skills in STEM education (Belland, 2008; Girault & Ham, 2014; Hmelo-Silver & Day, 1999). However, it is difficult for students to adjust to PBL if they approach ill-structured problem-solving the same way that they do well-structured problems (Hung, 2011; Jonassen, 2000). For successful learning in PBL for STEM education, therefore, students need help to generate solutions to complicated and ill-structured tasks, or problems (Moos & Azevedo, 2009).

Scaffolding, defined as support that helps students engage in and gain skill at tasks that are beyond their unassisted capabilities (Wood, Bruner, & Ross, 1976), has been widely utilized to overcome the above issue. Scaffolding can be classified according to modality (e.g., computer-based, teacher-based, and peer scaffolding), types (e.g., conceptual, metacognitive, strategic, and motivational), and context-specificity (generic and specific) (Belland, 2014, Hannafin, Land, & Olliver, 1999). Scaffolding has been effective in enhancing students' higher order thinking skills (Brophy, 1999; Pino-Pasternak & Whitebread, 2010), deep understanding of content knowledge (Azevedo, 2005; Linn, 2000), and argumentation skills (Liu & Bera, 2005; Sandoval & Reiser, 2004; Tsi, Lin, Shih, & Wu, 2015). Few studies have suggested a design framework of scaffolding that considers the characteristics of PBL. Authentic/ill-structured tasks of problem-based learning (PBL) are often beyond students' unaided ability, negatively influencing students' initial motivation and interest (Barrows, 1980; Savery & Duffy, 1995). Therefore, maintaining and enhancing students' engagement and motivation through scaffolding is important for them to perceive the given tasks in PBL as optimally challengeable (Belland, Kim, & Hannafin, 2013). In addition, most students have different levels of ability, interest, and motivation toward their learning. Nevertheless, most scaffolding utilized in the previous studies cannot be individualized, leading all students to receive the same scaffolding regardless of their learning needs (Puntambekar & Kolodner, 2005; Hsu, Lai, & Hsu, 2015). It remains unclear which characteristics of scaffolding should be designed to satisfy each student' diverse needs and different ability in PBL.

In the current literature, it may be difficult to generalize the effectiveness of scaffolding because learning environments, education level, and scaffolding interventions are so diverse. There have been attempts to synthesize the results from across studies through meta-analyses of scaffolding research (Belland, Walker, Olsen, & Leary, 2015; Lin, Ching, Ke, & Dwyer, 2007). However, the number of results from each condition was unbalanced and skewed towards certain areas (e.g., science, middle school students, conceptual scaffolding, and no fading). Therefore, an alternative method to analyze the effectiveness of scaffolding encompassing various conditions is needed.

In PBL, students should construct knowledge through scientific inquiry and the evaluation of claims. This means that information literacy, defined as an ability to identify which information is needed, search, evaluate and effectively utilize the information, is required for successful learning (Diekema, Holiday, & Leary, 2011). If students have adequate information literacy, information that they searched and validated can have significance as evidence to support their claims for problem-solving (Shorten & Crookes, 2001). It can also lead to improving students' argumentation skills to create the claim with the proper evidence while addressing ill-structured and authentic problems (Bruce, Edwards, & Lupton, 2006). Although some studies demonstrated the effectiveness of scaffolding in improving students' argumentation skills, few empirical studies investigated the impact of scaffolding on information literacy, argumentation skills within the same context, and how information literacy can have an impact on argumentation skills. Therefore, more studies are needed to demonstrate the effectiveness of scaffolding on information literacy, argumentation skills, and their relations.

The Multiple Paper Dissertation as Possible Solution

This multiple paper dissertation addressed the above-mentioned research gaps through three research articles. In it, I suggested and empirically tested a scaffolding design that can allow students to perceive a given task in problem-based learning as optimally challengeable. In the first paper, I advanced a conceptual framework to support this design. In the second paper, I used Bayesian meta-analysis to address the influence of scaffolding types and characteristics on cognitive outcomes in PBL for STEM education. Based on the first and second paper, I designed and developed computer-based scaffolding to help students enhance information literacy and argumentation skills as key elements for successful problem-based STEM education. The third paper reflected an empirical investigation of the effectiveness of the designed scaffolding.

Figure 1 illustrates the structure of this dissertation. Chapter II presents the design of scaffolding consisting of multiple types, sources, customization, and collaborative learning. In problem-based learning, ill-structured and authentic tasks are not always optimally designed for students who have diverse interests, knowledge, experiences, and learning skills. Therefore, students can lose their interest and motivation in learning due to the difficulty of tasks. Based on a distributed scaffolding approach (Puntambekar & Kolodner, 2005), team assisted individualization (Slavin, Madden, & Leavey, 1984), and flow (Csikszentmihalyi, 1988) and self-determination theories (Deci & Ryan, 2000), I proposed a scaffolding system (i.e., Learner-centered Scaffolding System) to improve and maintain student perception of optimal challenge within PBL curricula.

Building a conceptual framework is not enough to inform the design of scaffolding. I also need to refer to empirical data on the relative effectiveness of different scaffolding types and characteristics. To do this, meta-analysis has synthesized existing results from individual studies.

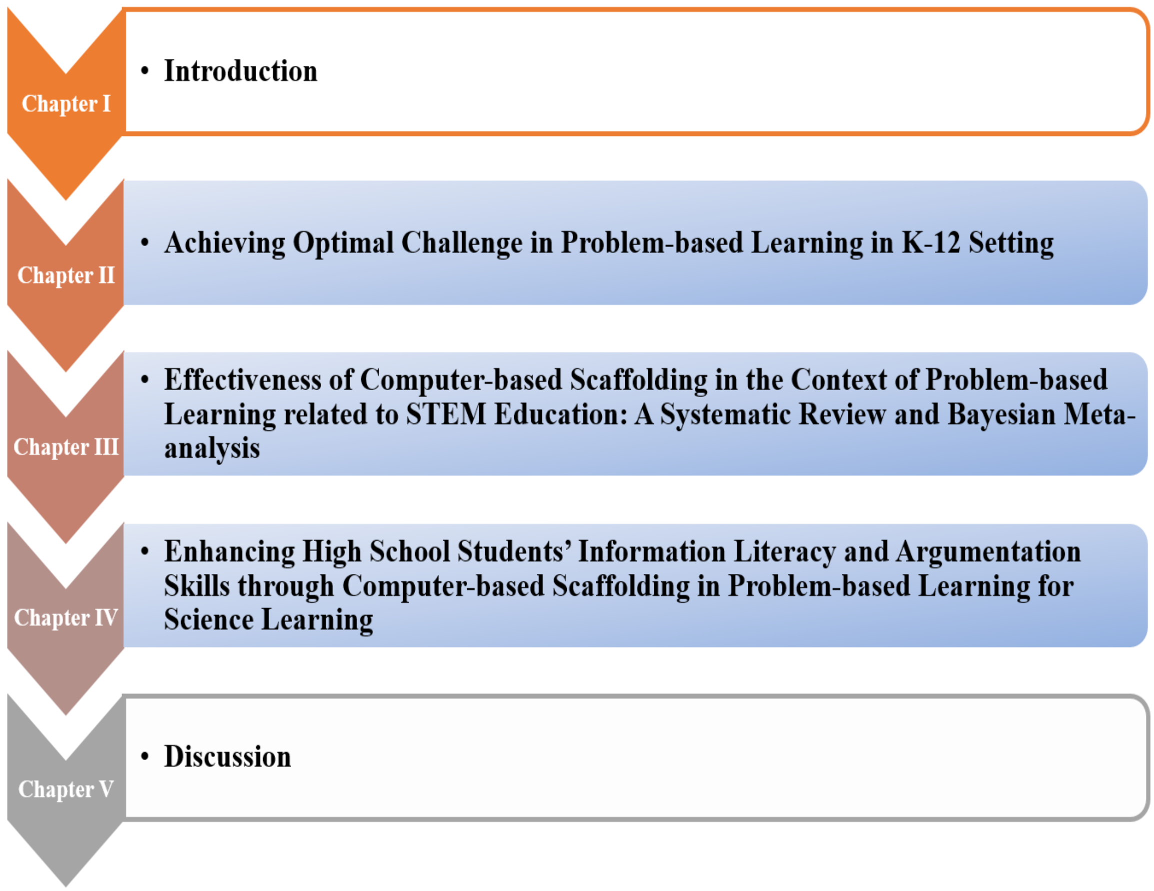


Figure 1. Dissertation structure.

However, learning environments are diverse, and traditional meta-analysis often suffers from uneven distribution for each condition. Therefore, chapter III employed Bayesian meta-analysis, which can effectively counter the uncertainty of unknown model parameters. This works by informing the current meta-analysis with a prior distribution and updating the distribution with new sample data from studies regardless of the number of studies. Moderators included scaffolding types (Belland, 2014), scaffolding formats (Puntambekar & Kolodner, 2005), scaffolding intervention types (Hannafin, Land, &

Oliver, 1999), intended outcomes (i.e., higher order thinking skills; Bloom, 1956), and scaffold customization.

Chapter IV reports an empirical investigation of the effectiveness of scaffolding that was informed by the first and second paper. Specifically, I investigated the effect of the scaffolding on high school students' information literacy and argumentation skills in science learning. In this paper, two types of computer-based scaffolding, *Virtual Field Trip (VFT)* and *Connection Log*, were used to help students to learn about 'air quality'. *VFT* provided real street views across cities, which allowed students to directly experience scientific phenomena. Students could gather real air quality data of an area where they "walk" around. Scaffolding embedded in the VFT helped students understand the concept of air quality, interpret air quality data, and determine the source of bad air quality. *Connection Log* was used to support student's argumentation. *Connection Log* steps enhanced students' ability to search for and justify information for their claim about solutions in PBL through individual and cooperative learning activities (Belland, 2010; Belland, Glazewski, & Richardson, 2011). Through a mixed method approach, this paper analyzed the effectiveness of computer-based scaffolding with various forms and timing in terms of students' information literacy and argumentation skills, which are regarded as important abilities to succeed in problem-centered instruction.

CHAPTER II

ACHIEVING OPTIMAL CHALLENGE IN PROBLEM-BASED LEARNING IN K-12 SETTINGS

Abstracts

Establishing optimal challenge enhances intrinsic motivation, interest, and the probability of success in the learning activity. In problem-based learning (PBL), students may struggle to address associated tasks that are beyond their current ability levels. This study suggested Learner-centered Scaffolding Systems (LSS) to improve students' perception of optimal challenge by addressing students' learning issues in PBL. LSS enhances students' experience in autonomy and competence by providing multiple types of scaffolding in accordance with student' different needs and difficulties in PBL. In addition, these multiple types of scaffolding can be effectively delivered to students through teachers and computer systems. Students can control the nature and frequency of scaffolding by themselves according to their needs and ability, and it plays a role in improving their self-directed learning skills. Last, peer scaffolding between students with the similar abilities satisfies students' needs for relatedness. Students' autonomy, competence, and relatedness can stimulate students' immersion and intrinsic motivation toward their learning. This, in turn, enhances students' perception of optimal challenge in the given tasks in PBL. As a consequence, student confidence to take on the ill-structured nature of PBL will increase and student problem-solving abilities will grow

Keywords: Optimal Challenge, Problem-based learning, Scaffolding

Introduction

Establishing optimal challenge refers to balancing learners' skill levels with appropriate task difficulty so as to maximize learning (Guadagnoli & Lee, 2004; Shernoff, 2013). Students who are optimally challenged experience a high level of intrinsic motivation, interest, and success in the learning activity because the task difficulty level is matched to each student's current ability level (Renninger & Hidi, 2015; Shernoff & Csikszentmihalyi, 2009). In teacher-directed classrooms, educators are responsible for moderating task difficulty and they do so though course sequence and problem selection (Sungur & Tekkaya, 2006). However, in more problem-centered and student-centered constructivist curricula, teachers lose much of their ability to effectively set an optimal level of challenge for each student due to the nature of addressing ill-structured tasks through self-directed learning (Hmelo-Silver & Barrows, 2015).

Problem-based learning (PBL) is characterized by ill-structured tasks, self-directed learning process, and a combination of individual and cooperative learning activities (Savery, 2015) and students may struggle to address associated tasks that are beyond their current ability levels (Wood, 2015). For example, the collaborative nature of PBL means that multiple students are tasked with confronting the exact same problem difficulty level regardless of their individual abilities (Savery, 2015). Instead, in PBL students are confronted with many different types of rigor brought on by deficiencies in knowledge or skills (Dolmans & Gijbels, 2013). Much of their success depend on how they find the right amount of personalized support and whether or not they believe that they can overcome their deficits with that support (Smith & Cook, 2012). It is these challenges that have led some researchers (Kirschner, Sweller, & Clark, 2006) to label instructional approaches such as PBL as instructionally ineffective. To the contrary, other researchers (Hmelo-Silver, Duncan, & Chinn, 2007) have argued that correctly implemented PBL curricula include extensive student support in the form of scaffolding, which helps students experience success even when facing these demands.

Scaffolding, defined as support to engage in and gain skill at the given tasks beyond their existing capabilities (Wood, Bruner, & Ross, 1976), can help students address challenges related to a lack of content-knowledge, transfer of knowledge, and motivation that can be experienced during PBL (Schmidt, Rotgans, & Yew, 2011; Simons & Klein, 2007). More support would lead to more success and which in turn can negatively or positively impact perceptions of optimal challenge. However, a recent synthesis of problem-centered educational models including PBL showed a large difference between learning gains of different age groups that all received support (Belland, Walker, Kim, & Lefler, in press). Belland et al. (in press) reported a sharp decline in the effectiveness of scaffolded PBL curriculum as ages decreased from adults ($g = .86$) and graduate populations ($g = .61$) to secondary ($g = .48$) and middle grade students ($g = .37$). One possible explanation is that PBL originated in medical schools, which serves a highly motivated and highly self-directed student population, which also has a relatively homogeneous set of domain-specific knowledge and advanced problem-solving skills (Barrows, 1996). In contrast to medical students, middle and secondary students not only lack requisite knowledge and skills but may also not be motivated by their curriculum nor even experience adequate support from their teachers (Torp & Sage, 1998). In this sense, although the difficulty level of PBL tasks can be optimized based on students' level, optimal challenge itself by balancing task difficulty may not guarantee success. This is because PBL depends on the student's perception of task difficulty and their perception of their own ability to tackle that problem successfully. Optimal challenge in PBL is about moderating task to students' current ability but also about moderating student self-efficacy. Thus, in order to have K-12 students experience success at the same level of their older counterparts, they must receive additional scaffolding supports so as to experience optimal challenge. The purpose of this theoretical paper is to put forth a design of scaffolding system to help K-12 students overcome the specific issues they face in PBL such as a lack of domain-specific knowledge, problem-solving skills, self-direction, and collaborative skills.

The Concept of Optimal Challenge

Optimal challenge maximizes learning by balancing learner skill level and task difficulty (Soltani, Roslan, Abdullah, & Jan, 2011). If tasks do not correspond well to students' ability levels, various side effects can occur (Guadagnoli & Lee, 2004; Shernoff, 2013). For instance, when a high difficulty task is assigned to a lower-achieving student, the student can become anxious and disengaged (Sarason & Palola, 1960; Willingham, 2009). Assigning a low difficulty task to a higher-achieving student leads to boredom and apathy (Rheinberg & Vollmeyer, 2003; Tozman, Magdas, MacDougall, & Vollmeyer, 2015). The importance of providing students optimal challenge is that it can keep stimulating and maintaining their intrinsic motivation toward their learning, and it can increase the chance of success in learning. The impact of optimal challenge has been demonstrated by previous studies. When the challenge of the learning task was optimally suited for each student's particular ability, students from elementary school to even adults spent more time on their learning (Mandigo & Holt, 2006) and improved understanding of content knowledge and actively engaged in their learning (Durr, 2009; Harter, 1978; Liu, Li, & Santhanam, 2007) in the various subjects within diverse learning environments. In addition, when students had the authority to choose the task difficulty, most students selected a difficulty level aligned with their current ability, which in turn allowed them to successfully finish their learning tasks (Sit et al., 2010).

It is important to note that challenge optimization is not just a single event but an ongoing process. In a PBL, students are provided with an authentic problem to solve and then expected to move through a series of seven sub-tasks (e.g., problem statement, information search, claim generation) in order to arrive at a final solution (Savery, 2015). Each sub-task is associated with a challenge level that would need to be moderated such that the student would continue to have success at each stage. This would entail a balancing of the learner proficiency at each specific sub-task since a student may perceive writing up a problem statement as optimally challenging, only to be overwhelmed with the next task of identifying information (Pedersen & Liu, 2002; Simons & Klein, 2007). However, managing optimal challenge for just one student could prove difficult considering the high variability that could exist not only in the ranges of task difficulty but also with respect to variability in student proficiency with those tasks. This issue is then further complicated when one considers that K-12 classrooms often have one teacher for every 25+ students. Instead of putting teachers in the precarious position of constant student assessment and task manipulation, it would be better to supply scaffolds that automate this process (Postholm, 2006).

The following theories can explain why optimal challenge in PBL is important for successful learning and inform guidelines about how scaffolding should be designed to allow students to perceive optimal challenge (see Figure 1).

Flow Theory

Flow is a psychological state in which one can forget the passage of time and space, being deeply immersed in a certain activity (Csikszentmihalyi, 1988). Flow leads to optimal experience, in which attention is freely utilized only to attain goals because students are not distracted by external events (Csiksczentmihalyi, Kolo, & Baur, 2004). Flow state induces students to keep working through maximization of direct and intrinsic rewards. To promote flow, instructors need to provide intellectually demanding tasks. Three conditions promote flow - clear goals, immediate/formative feedback, and balance between perceived challenge and perceived skills (Csikszentmihalyi, 1996).

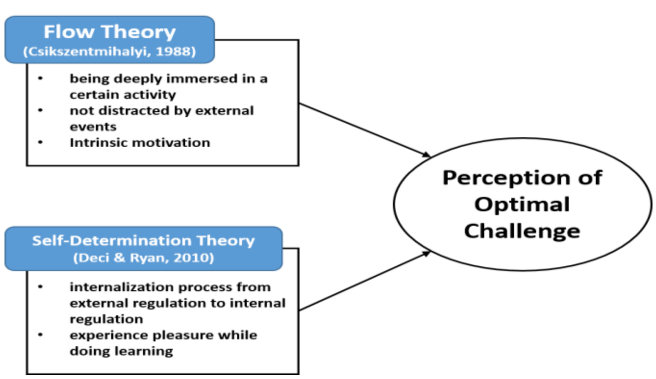


Figure 1. Prerequisites for experiencing optimal challenge.

If students' perceived skill levels are well aligned with the perceived challenge of the task, students' concentration on the task is more likely to occur. Flow state is not the only factor that affects students' involvement in learning activities. If they conduct a task due to extrinsic motives, students may prefer to do easier and more doable tasks.

Self-Determination Theory

Self-determination theory (SDT) emphasizes the importance of intrinsic motivation on cognitive and social development through the active engagement in learning (Deci & Ryan, 2000). From the perspective of SDT, human beings practice self-determination as they proactively respond with interest to environmental challenges with their social groups (Deci & Vansteenkiste, 2004). SDT, therefore, emphasizes that optimal learning in educational contexts is achieved as extrinsic motivation is transformed into intrinsic motivation, which enables the student to better self-regulate (Niemiec & Ryan, 2009). Typically, students who are self-regulated experience greater level of intrinsic motivation, which helps them to maintain their interest and effort (Ryan, Connell, & Grolnick, 1992). It is important to consider the fact that though a given task may satisfy students' current abilities and needs, it may not always connect with students' intrinsic motivation. To optimally and effectively develop students' potential and enhance intrinsic motivation, Deci and Ryan (2002) highlighted three essential psychological needs: a) autonomy, b) competence, and c) relatedness. *Autonomy* can be achieved as students control their own behavior and *competence* can be achieved when students experience success at tasks that they perceive to be difficult. Furthermore, students experience *relatedness* when they perceive a sense of belonging to the community (Deci & Ryan, 2000). By addressing these needs, students can experience an internalization process from external regulation to internal regulation as well as sustain their intrinsic motivation toward the learning activities (Deci, Koestner, & Ryan, 1999; Deci & Ryan, 2000, 2010). However, not all learning environments have the requisite characteristics to foster autonomy, competence, and relatedness in students. Learning curricula that are more teacher-centered will impede the development of self-regulation, whereas curricula that are more social, problem-centered and student directed such as PBL provide students a space, in which they can develop greater self-regulation.

Problem-Based Learning

Problem-based learning is a learner-centered and problem-centered instructional model, in which students engage in authentic and ill-structured problems (Savery, 2015). Students acquire new knowledge by identification of knowledge gaps between their current level of knowledge and the level of knowledge it would take them to address the given problem (Barrows, 1996; Savery, 2015). Barrows and Myers (1993) defined PBL as a multi-step approach, in which small groups composed of five students work with one tutor who is assigned exclusively to a single group. After a problem is provided to students, students discuss the problem, generate hypotheses, and develop learning goals. Next, they collect needed information, and through discussions with their small group, evaluate the usefulness of their collected information and resources to determine whether more information is required to confidently make a supported claim. This process is iterative until a refined problem solution can be adopted by the group members' consensus.

Tasks in PBL

Tasks in PBL are ill-structured, which means that they (a) can be defined and addressed in multiple ways, and (b) have many satisfactory solutions. Ill-structured problems are a possible way to strike a balance between task difficulty and individual ability in that they have multiple potential solution paths (Jonassen, 2000). Students must be able to devise a solution path according to their ability and sometimes choose one path out of many in order to solve a problem. As students achieve success at this matched rigor level, their motivation, in particular, self-determination and self-efficacy, increases while at the same time the chance of learned helplessness/frustration decreases (Carli, Fave, & Massimini, 1988; Clarke & Haworth, 1994). These complex and challenging activities also increase the chances that students will experience a flow state by an internal reward from feeling successful in the problem-solving process. If students can adjust well to ill-structured tasks in PBL, PBL can be the effective instructional model for them to perceive optimal challenge by actively engaging in the learning process with their own research strategies (Mauffette, Kandlbinder, & Soucisse, 2004). Figure 2 shows how students can experience optimal challenge within PBL

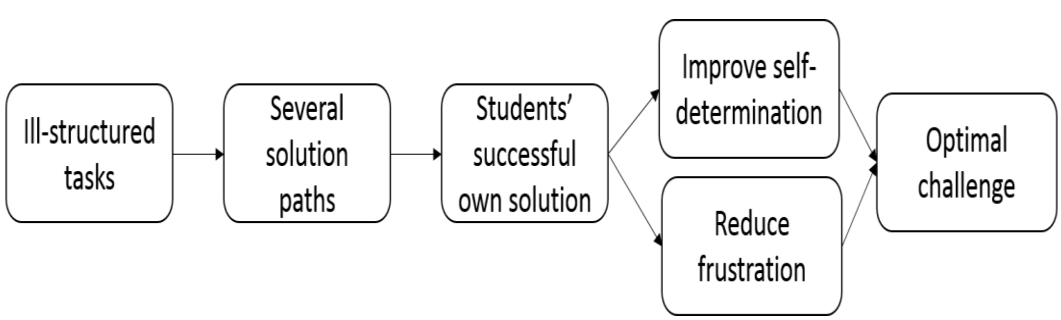


Figure 2. Ill-structured tasks in PBL.

Fostering Self-determination in PBL

In addition to content knowledge, students may also acquire additional capacities including self-directed learning, problem-solving, and acquisition of cooperative learning skills (Barrows & Myers, 1993). The design of PBL fosters student self-determination by addressing the aforementioned psychological needs of autonomy, competence, and relatedness (Müller & Louw, 2004). PBL enhances students' *autonomy* in that students need to take the initiative in learning (Chirkov & Ryan, 2001). This happens in PBL as the teacher's role is relabeled as one of a facilitating tutor, which minimizes a teacher's control over the learning process and allows students to experience a greater level autonomy. This new teacher-student relationship requires students to assume greater responsibility over their learning than in teacher-led instruction (Mills, Treagust, & others, 2003; Reeve, Jang, Hardre, & Omura, 2002). Group collaboration is also an essential feature of PBL and fosters r*elatedness* (Hmelo-Silver & Barrows, 2015). If the quality of teacher-student and student-student relationships in PBL collaboration is positive then students will feel safe and their need for relatedness will be satisfied (Ferrer-Caja & Weiss, 2000). Additionally, PBL can also enhance *competence* as students experience success in tackling the rigor of ill-structured problems on their own (Chirkov & Ryan, 2001). As students satisfy their psychological needs in PBL, they will experience internalization of their motivation (Deci & Ryan, 2000). Furthermore, when intrinsically motivated, students will want to engage with tasks for longer periods and experience pleasure while doing so (Pelletier et al., 1995). For this to be achieved, the given tasks in PBL should be optimally challenging but this may prove to be difficult especially in younger grade levels where students work in groups with a much greater level of proficiency disparity (Cela, Sicilia, & Sánchez-Alonso, 2015; Kaufman, Felder, & Fuller, 1999).

Originally PBL was designed for medical students but the model has been revised for use among various age ranges, subjects, and educational institutions, including business, educational psychology, K-12 (e.g., science, engineering, technology, and mathematics) and higher education (e.g., undergraduate disciplines and vocational education; (Delisle, 1997; Hmelo-Silver, 2004; Torp & Sage, 1998) Meta-analyses by Gijbels, Dochy, Bossche, & Segers (2005) and Leary, Walker, & Shelton (2012) have shown that PBL improved understanding of content knowledge and self-directed learning. Nevertheless, some scholars questioned the effectiveness of PBL on K-12 students who do not have much experience in self-directed learning and reflective thinking (e.g., Koh, Khoo, Wong, & Koh, 2008). For example, it might be difficult for younger students to be deeply immersed in a certain activity in PBL, which simultaneously requires them to improve their content knowledge and problem-solving skills in addition to their self-regulation and intrinsic motivation (Koh et al, 2008; Salam et al., 2009).

To address this issue, scaffolding can be utilized to enhance student's engagement and to build their higher-order skills in complex learning contexts (Belland, 2014; Hannafin et al., 1999; Tuckman & Schouwenburg, 2004). However, it is not clear how scaffolding can affect students' perception of optimal challenge in PBL by enhancing their flow and intrinsic motivation toward learning due to a lack of studies.

Students' Challenges and Scaffolding Design in PBL

PBL requires students' diverse skills such as effective problem-solving skills, self-directed learning skills, and interpersonal skills as well as flexible knowledge (Gallagher, Sher, Stepien, & Workman, 1995). Thus, it is possible for students to experience several types of difficulties during PBL because of students' different levels of background knowledge, learning skills, and motivation. If students experience any difficulties in PBL, it hinders students' immersion in learning, and worsens students' recognition of optimal challenge due to a lack of intrinsic motivation by the reduction of autonomy, competence, and relatedness (Wijnia, Loyens, Derous, & Schmidt, 2015). In this section I describe the obstacles (i.e., the complicated process, a lack of qualified facilitator, self-directed learning, and collaborative learning) hindering students' perception of optimal challenge in PBL and also suggests the design of scaffolding called "Learner-centered Scaffolding Systems (LSS)" to improve students' perception of optimal challenge by addressing students' learning issues in PBL (see Figure 3).

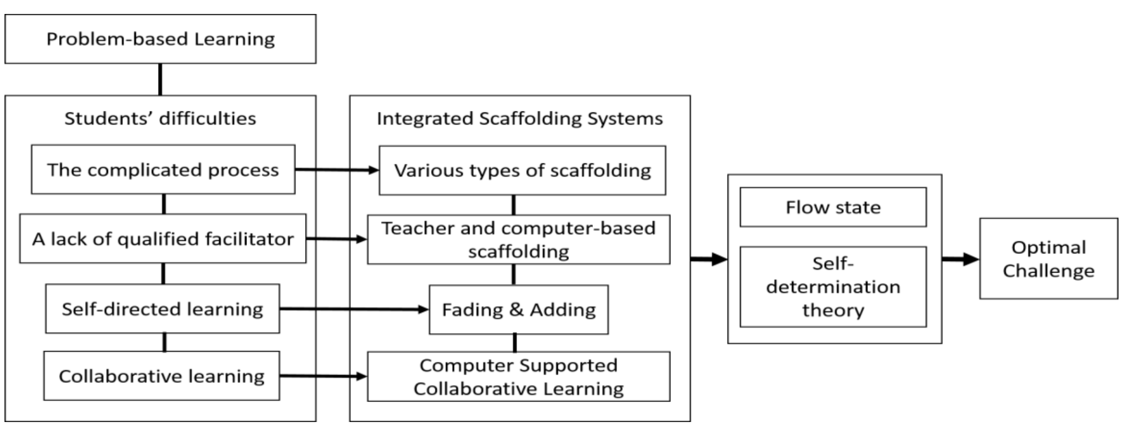


Figure 3. Students' challenges in PBL and scaffolding design for addressing their challenges.

Learning Process in PBL

Students' difficulties. Students in PBL face ill-structured problems that are intertwined with their real life (Hmelo-Silver, 2004). That is, students should solve real-life problems that human beings can experience and they actively engage in learning activities to generate various reasonable solutions by connecting new information to their existing knowledge (Jonassen & Hung, 2008). When students try to solve this type of problems by themselves, they can perceive the given tasks as personally meaningful, and improve their intrinsic motivation (Loyens, Magda, & Rikers, 2008). However, one issue is the complicated and unfamiliar problem-solving process in PBL (Savery, 2015). The process of PBL consists of four major steps- a) defining problems, b) determining information for addressing the problems, c) finding, evaluating, and utilizing information as evidence for their solutions, and d) generating an argument in support of the solution (Belland, Glazewski, & Richardson, 2011). Each step is intimately connected to the another, and if students cannot accomplish the task from a certain step, it will be increasingly difficult to successfully complete subsequent steps. Furthermore, at each step students have to deploy different abilities and skills. For example, students need domain and structural knowledge to understand and define the problems in the first step of PBL (Barrows, 1994). Additionally, they must use high levels of metacognition as they consider where and when domain knowledge can be utilized as they devise their own strategies for problem-solving (Hmelo-Silver & Barrows, 2015). This means that K-12 students, who quickly solve well-structured problems with information provided by teachers, could have difficulty adjusting to the ill-structured problems of PBL, which require advanced problem-solving skills. Students who have previously experienced success in teacher-led classrooms may experience much more difficulty solving PBL problems as they confront deficits in their content knowledge, problem-solving skills, self-determination, and motivation. For all these reasons, students with larger deficits may need a greater level of support to experience success. To address this, this paper suggests various types of scaffolding (see Figure 4)

Suggested scaffolding. The original definition of scaffolding focused on developing students' problem-solving skills by providing just-in-time support (Wood et al., 1976). But recently, the role of scaffolding has been expanded into enhancing content knowledge and other skills such as self-determined learning and argumentation skills (Belland, 2010; Kek & Huijser, 2011; Leary et al., 2012). Moreover, to promote the perception of optimal challenge, scaffolding should also play a role in enhancing motivation, including self-efficacy (Belland, Kim, & Hannafin, 2013; Bixler, 2007; Tuckman, 2007).

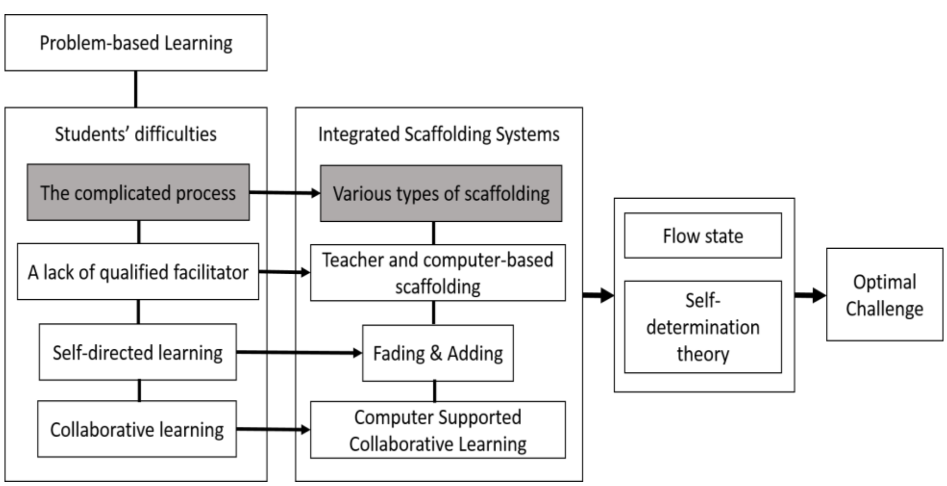


Figure 4. Several types of scaffolding.

Students motivation and confidence can be enhanced or weakened for a variety of reasons, and various types of scaffolding should be provided to students according to their current situation (Belland et al., 2013). For example, scaffolding that arouses interest can be used to enhance motivation among students who often exhibit low interest in academic tasks. On the other hand, for students who have difficulty in solving problems, scaffolding to enhance content knowledge understanding is needed (Hannafin, Land, & Oliver, 1999). In this sense, scaffolding can be divided into four types - conceptual, metacognitive, strategic, and motivation scaffolds (Collins, Brown, & Newman, 1989; Hannafin et al., 1999; Tuckman & Schouwenburg, 2004) (see Table 1).

Conceptual scaffolding provides hints and prompts about the content (Hannafin et al., 1999), and it helps to structure and problematize tasks (Reiser, 2004). Conceptual scaffolding often incorporates such strategies as concept mapping and other visualization strategies. In the first step of PBL, conceptual scaffolding helps students feel that the given problem is worth attempting and spending time by providing the reason why the given problem is important to their life and by linking the problematic situation with their own experience. It, in turn, enhances students' intrinsic motivation and makes it for students to easily adjust to authentic problems in PBL.

Metacognitive scaffolding invites students to reflect on their learning process and encourages students to consider possible problem solutions (Hannafin et al., 1999; Oliver & Hannafin, 2000). In PBL, students' recognition of what they already know and should know is important to establish the learning plan and strategy. In this sense, metacognitive scaffolding provides students the chance to define the problem based on their prior

Table 1

Examples of Various Types of Scaffolding

Type of scaffolding	Examples	References
Conceptual scaffolding	"If you are trying to calculate the weight and the gravitational acceleration along an axis, here is a general formula that always works: Let θV be the angle as you move counterclockwise from the horizontal…."	(Vanlehn et al., 2005, p.155)
Metacognitive scaffolding	"Did you write your goal statement as planned?", "How are you going to choose the country?"	(Molenaar, Boxtel, & Sleegers, 2011, p.801)
	"Why did you feel feature x was important in coming to a diagnosis?", "What feature(s) do you think is the most crucial in coming to the diagnosis of this case?"	(Roll, Aleven, McLaren, & Koedinger, 2007, p.28)
Strategic scaffolding	"Draw a model for the structural formula of C_5H_8 you suggested", "Write the structural formula of propylene glycol – a product of a reaction between propane, $KMNO_4$, and water"	(Kaberman & Dori, 2009, p. 606)
Motivational scaffolding	"You're feeling less overwhelmed now that you've found it's not hard at all?" "Very nice. And I think that's a difficult thing for lots of students to achieve in their writing."	(Mackiewicz & Thompson, 2014)

experience and knowledge. Strategic scaffolding focuses on processes to solve problems and provides guidance about problem-solving strategies such as providing the information of resources utilized in solving the problems (Hannafin et al., 1999). The key to success in PBL depends on how students can determine the most proper information for evidence of their own solution and generate the reasonable solutions based on evidence. Strategic scaffolding in PBL can be a systematic procedure of PBL, which helps students' problem-solving process. This scaffolding clearly divides the PBL process into five steps, and students' tasks in each section are assigned to improve students' learning strategy for their own research along with the experts' learning strategy (Belland et al., 2011).

Motivational scaffolding plays a role in enhancing students' interest, confidence, and collaboration (Rebolledo-Mendez, Boulay, & Luckin, 2006; Tuckman & Schouwenburg, 2004). There is a lack of research utilizing motivational scaffolding in PBL, but students' motivation is an important factor in the enhancement of students' perception of optimal challenge in PBL (Belland, 2014). Certainly, as students accomplish their tasks by supports from conceptual, metacognitive, and strategic scaffolding, their motivation can improve. However, it is clear that motivational scaffolding is required to directly improve students' ability to persist confidently as they face the difficulties proceeding from their learning. In PBL, students often struggle due to a lack of content knowledge, metacognition, learning strategy, and interests in PBL. If appropriate and just-in-time supports for addressing these various difficulties are not provided, students may not perceive optimal challenge. For example, as seen in Figure 5, when ill-structured/authentic tasks are given at the beginning, students can struggle to understand and define the given problems due to a lack of content knowledge. At this moment, conceptual scaffolding among various types of scaffolding can be intensively provided to help students structure their content knowledge. On the other hand, a strategic scaffold in the form of problem-solving strategy may be outlined so that the student can imagine a way forward. However, expertly providing all four types of scaffolding is easier said than done.

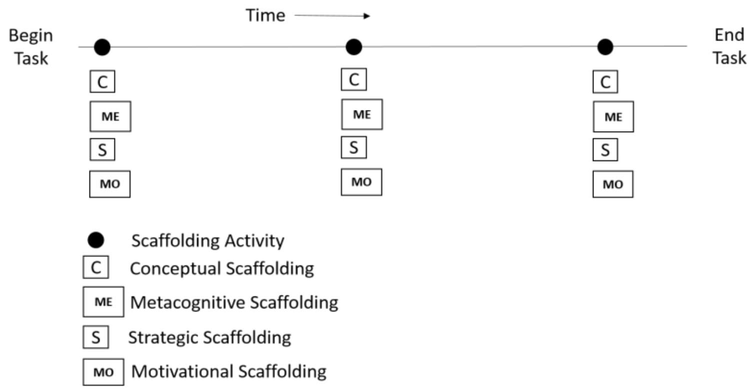


Figure 5. Four types of scaffolding.

The Problem Facing K-12 PBL Facilitators

Students' difficulties. When first developed in the 1960's, PBL was meant to help medical students enhance problem-solving and self-directed learning skills, as well as content knowledge, by addressing ill-structured, authentic medical problems (Barrows, 1994). Today, PBL is also used in such fields as economics, architecture, and nursing (Boud & Feletti, 1998; Gijselaers, 1995). Moreover, it is actively applied in primary and secondary schools (Sage & Torp, 2002; Stepien & Gallagher, 1993). One of the biggest differences between PBL's medical school roots and the current content areas of PBL is the role of the facilitator (Johnston & Tinning, 2001). PBL facilitators in medical school get professional training about their roles, which a) help students recognize the problematic situation by themselves, b) stimulate students' advanced thinking process and knowledge integration skills, c) inform the learning process, and c) induce the evaluation of group members' opinions and works through active interaction (Dolmans et al., 2002). These scaffolds from facilitators can improve students' anatomy, competence, and relatedness for enhancing their intrinsic motivation, which would ultimately result in students' perception of optimal challenge (Belland et al., 2013). Therefore, it is important for facilitators to check each student's current learning status through continuous diagnosis for providing proper and just-in-time supports. PBL environments in medical field enable this because facilitators can specifically check the group members' learning status and needs due to a small number of students (Johnston & Tinning, 2001). Furthermore, students in medical school have similar learning goals, knowledge background, and learning ability, which decreases the facilitators workload. However, K-12 teachers often lack mastery of the skills required to effectively fulfill the role of facilitator due to a lack of the professional training for PBL (Johnston & Tinning, 2001). Additionally, K-12 teachers will most likely be unreasonably required to provide support for 25+ students simultaneously. This makes it difficult for teachers as facilitators to provide suitable scaffolding to address every student' current needs occurred during PBL. If teachers do not respond adequately to students' difficulties, students can lose sight of the learning goals and how to achieve them. Therefore, students need some additional sources of scaffolding for immediate and adequate supports. To address this issue, this paper suggests multiple sources of scaffolding (see Figure 6).

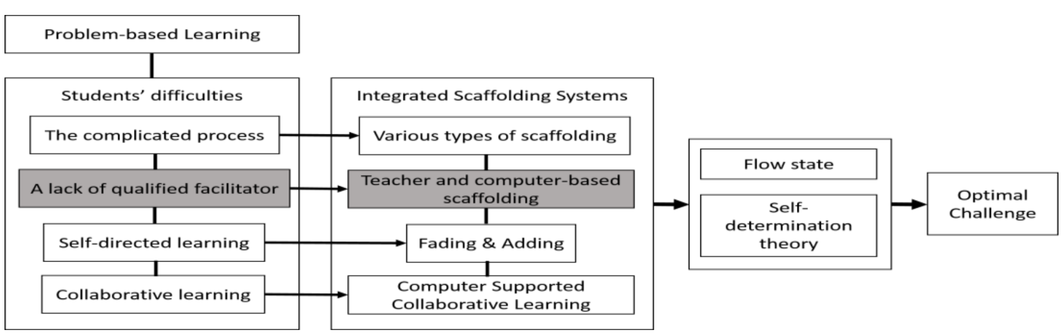


Figure 6. Multiple sources of scaffolding.

Suggested scaffolding. The source of scaffolding indicates how scaffolding can be delivered to students (Belland, 2014). Typically, scaffolding can be provided by teachers, computer systems, and peers. Teacher scaffolding consists of one to one support for student learning, often in the form of probing questions, prompts to action or illustrations that help students organize their thinking (Belland et al., 2013; Zhang, 2013). Computer-based scaffolding is often categorized as hard scaffolds (Saye & Brush, 2002), which are designed to address predictable difficulties presented by the embedded systems within a certain software. Intelligent tutoring systems can provide more individualized and just-in-time supports by addressing the issues of the existing computer-based scaffolding such as an inherent lack of immediate adaptability to student needs. However, intelligent tutoring systems often are ill-equipped to differentiate between students' deep and shallow learning (Koedinger & Aleven, 2007). Collaboration with peers who have better knowledge and ability can be an effective scaffolding source to improve students' higher order skills and motivation (Gillies, 2008; Oh & Jonassen, 2007). However, in the case of peer scaffolding, it may be unreasonable to expect peers who have the similar level of knowledge and ability to provide sophisticated scaffolding of all types to each other. That is, peer scaffolding might not be suitable as a main delivery method for metacognitive and strategic scaffolding, which may be beyond the ability of a peer to explain or correctly apply. In this sense, teacher scaffolding and computer-based scaffolding are preferred to effectively deliver the diverse types of scaffolding. Peer-scaffolding is handled as an effective means for collaborative learning in the next section.

Scaffolding provided by teachers might fit well when the respect for authority is part of the student's culture, epistemic belief system or gender preference (Pata, Lehtinen, & Sarapuu, 2006; Van de Pol, Volman, & Beishuizen, 2010). In addition, teachers can exactly diagnose students' current needs and learning status, thereby providing more effective scaffolding to students. However, one teacher cannot provide immediate feedback to every student when classrooms contain 20-30 students (Wu, 2010). Computer-based scaffolding, therefore, can play a role in supporting teacher-based scaffolding through generic or context-specific supports (Wu, 2010). Computer-based scaffolding can provide immediate feedback based on students' performance (Belland, 2014). Intelligent tutoring systems (ITS) use artificial intelligence technology to recognize students' different ability levels, and provide immediate feedback based on students' current understanding (Anderson, Corbett, Koedinger, & Pelletier, 1995; Fletcher, 2003; Plano, 2004). But ITS can elicit surface approaches to learning in that students often try to receive as much help including hints as possible to solve the problem faster, disregarding their learning progress (Koedinger & Aleven, 2007). There is no method to control for students' unconditional requests of scaffolding within ITS because current computer systems cannot still judge whether the requested scaffolding is absolutely essential for learning. Thus, it cannot help but provide undifferentiated and simple help (Jonassen & Reeves, 1996). This means that computer-based scaffolding cannot completely replace teacher scaffolding in PBL.

If teacher scaffolding with just-in-time and elaborated supports and computer-based scaffolding with immediate supports can be well-combined, scaffolding can be delivered to students more efficiently and effectively. For example, computer-based scaffolding can recognize the steps that students are performing, and present various types of scaffolds to students corresponding to their learning process. If students cannot satisfy computer-based scaffolding to address their current learning issue, teachers, then, can provide individualized and sophisticated supports. In this case, teachers can greatly reduce the burden as a scaffolding provider because they only handle students who need more advanced supports. Figure 7 illustrates this system. Multiple sources of scaffolding (e.g., teacher-provided and computer tools) have been provided in several studies (Kajamies, Vauras, & Kinnunen, 2010; Roschelle et al., 2010). Those studies provided generic supports from computer systems and the more specific individualized supports from teachers as needed. The results showed that students who got teacher- and computer-based scaffolding as needed showed better problem-solving skills than those who received teacher's help or computer-based supports alone.

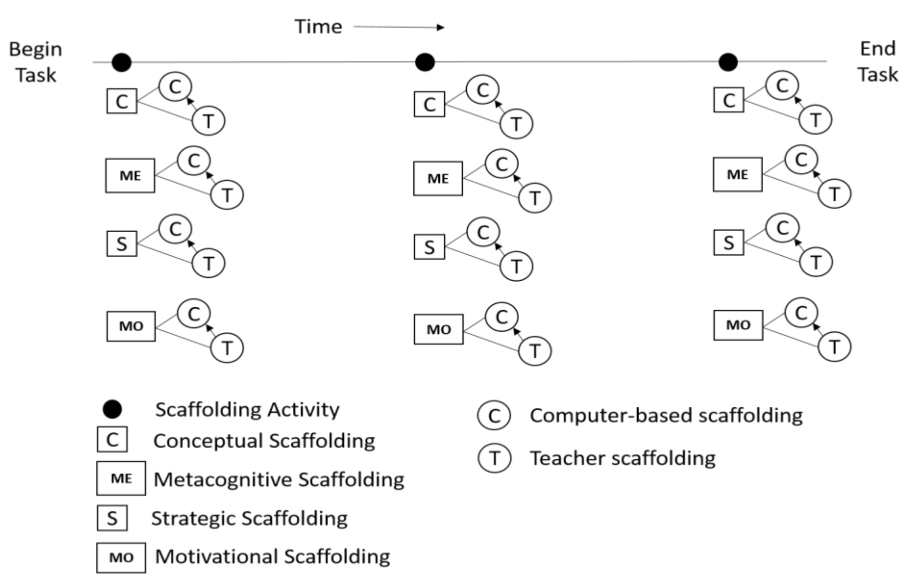


Figure 7. The sources of scaffolding.

Self-directed Learning in PBL

Students' challenges. One of the characteristics of problem-based learning is that learning is done through self-direction (Hmelo & Lin, 2000; Loyens et al., 2008). Knowledge acquisition is always the product of self-directed learning with the authentic problems according to constructivist perspective (Leask & Younie, 2001). Thus, if learning is an active and constructive process, the role of learners should establish the learning goal and strategies in the knowledge construction activities. Learners' self-directedness becomes the precondition for learning, but is also a requirement to encourage transfer. Self-direction allows learners to participate more actively in the learning process, and take responsibility for their learning (Rieber, 1991). Specifically in PBL, self-directed learning can boost metacognitive skills and intrinsic motivation to further encourage the learners' efforts in understanding of the given problematic situation, the organization of information, generation of multiple solutions, and self-evaluation (Loyens et al., 2008). Therefore, if learners are given control over their learning, they will be able to improve self-directed learning skills to take a lead and reflect on their learning and performance. This, in turn, leads to students' perception of optimal challenge due to the improved autonomy and confidence of their learning. However, it might be difficult to expect that K-12 students easily adjust to self-directed learning in PBL. When K-12 students, who are familiar with the learning objectives and plan decided by teachers, first attempt to self-direct learning in PBL, they experience a lot of difficulties and trial and errors (Loyens et al., 2008). This can reduce students' confidence in accomplishing the tasks and motivation. It makes it difficult for students to proceed their learning with the recognition of optimal challenge. This paper suggests fading and adding scaffolding to improve students' self-directed learning (see Figure 8).

Suggested scaffolding. Three kinds of scaffolding customization (i.e., fading, adding, fading/adding supports) considering students' self-directed learning are required to maintain optimal challenge. There are three bases of scaffolding fading, adding, and fading/adding: fixed-time interval, performance, and self-selection. Fixed time interval means that fading, adding, and fading adding occurs after a pre-defined number of events or after a fixed time interval. The frequency and nature of scaffolding can be changed by students' current learning performance and status. Lastly, students can request fading, adding, and both of them based on their decision as mentioning or clicking the button of "I don't need this help anymore" or "I need more supports"

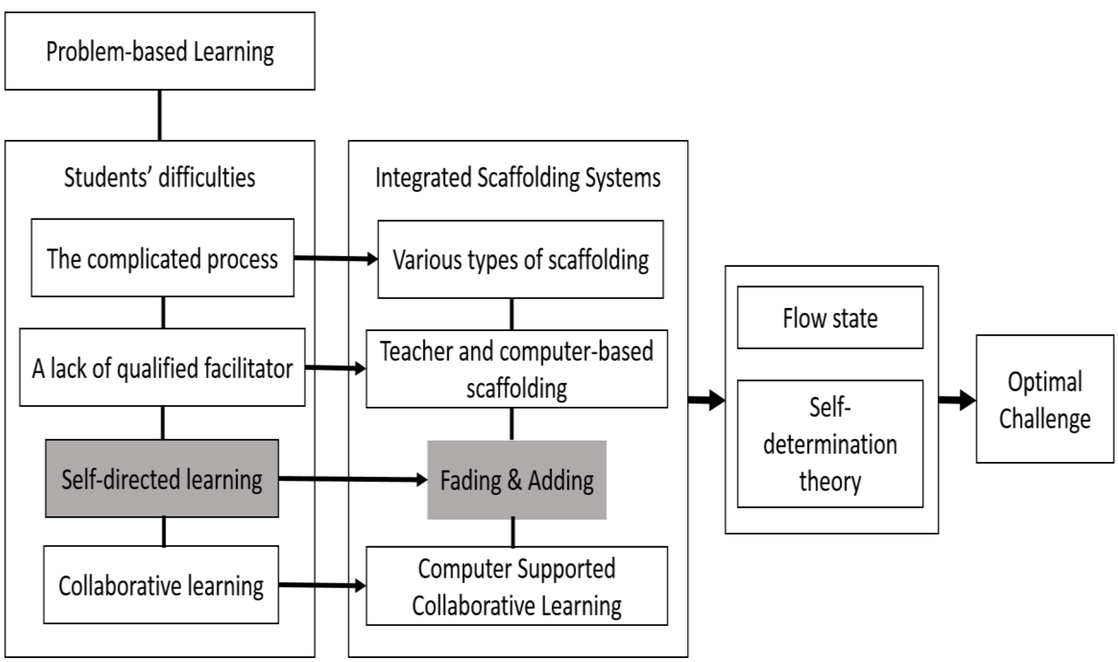


Figure 8. Fading/adding of scaffolding.

Fading. If scaffolding worked successfully, students should be ultimately able to reach the desired goal without scaffolding (Collins et al., 1989; Fretz et al., 2002; Hoffman, Wu, Krajcik, & Soloway, 2003). By effectively controlling the timing and degree of scaffolding, students can take the responsibility for their learning process (Chang, Sung, & Chen, 2002). This can lead to self-directed learning (Loyens et al., 2008). It is very difficult, in computer-based instruction, to diagnose students' state of understanding, motivation, and metacognition (Azevedo, Cromley, & Seibert, 2004; Clarebout & Elen, 2006; Lee, Lee, Leu, & others, 2008; Ruzhitskaya, 2011). Most computer-based scaffolding that incorporates fading employs fixed fading, in which scaffolds are removed after a fixed time interval and are thus not completely adapted to student ability. Many intelligent tutoring systems implement performance-adapted fading based on assessment of student performance (VanLehn, 2008), but many scholars criticized the use of fading by computer systems due to inaccurate diagnosis of students' behavior, intention, and learning progress (Jackson, Krajcik, & Soloway, 1998; Jonassen & Reeves, 1996; Madaio, 2015).

In the case of fading by teachers' judgment, teachers need to determine the timing of fading as a result of examining each student's learning process. So, teacher-controlled fading tends to be performance-adapted based on students' performance (Chin, 2007). In the case of performance-adapted fading by teachers, it might not be feasible for one teacher in the classroom to identify the degree to which each student has mastered the target content due to the number of students (Wu & Pedersen, 2011). Considering optimal challenge, it is important to base fading decisions on the exact diagnosis of students’ current understanding because the suitable timing of fading must maintain the balance between the difficulty of task and students’ ability. However, it is very difficult for computers and teachers to determine the timing of fading based on ongoing diagnosis of students’ current understanding due to the limitation of technology and current classroom environment. Therefore, one alternative fading method for optimal challenge should be considered.

In PBL students have ownership of their learning (Wood, 2015), and take responsibility for their learning process and strategy (Hoffman & Ritchie, 1997). This indicated that PBL requires self-directed learners who can control over their learning as selecting learning materials and the strength or frequency of supports by autonomy (Loyens et al., 2008; McLoughlin & Lee, 2010). In this sense, self-selected fading can be one method of fading for optimal challenge. Certainly, it is possible that students misjudge their understanding of learning, and make poor instructional decisions (Aleven & Koedinger, 2002; Hadwin & Winne, 2001). But self-confidence and motivation may be enhanced through the use of self-selected fading because in this way, students can control their own learning (Ryan & Deci, 2000). They can maintain a state of optimal challenge through self-selecting fading and conducting learning efficiently by eliminating unnecessary scaffolding. In other words, considering the goal of fading for optimal challenge to help students reach the final learning goal by their own learning strategies, self-selected fading can be a good method to improve students’ self-confidence for the successful accomplishment of tasks as effectively controlling the timing and degree of fading by themselves. This claim has been proven by Bayesian meta-analysis on the effectiveness of computer-based scaffolding in PBL in which self-selected scaffolding customization was the best choice to directly improve students' learning performance rather than the change of scaffolding by performance-adapted and fixed-time interval (Kim, Belland, & Walker, 2016). Therefore, if the limitation of self-selected fading above mentioned (i.e., students' insufficient ability to diagnose their learning process and to figure out whether scaffolding is still needed or not) can be overcome, self-selected fading can be helpful for students to maintain the perception of optimal challenge in PBL. The possible solution is that teachers and computers can play a role in supporting self-selected fading. In other words, students can fade scaffolding by themselves, but when their decision of fading is problematic, computers and teachers can invite students to reflect on their decisions (See Figure 9).

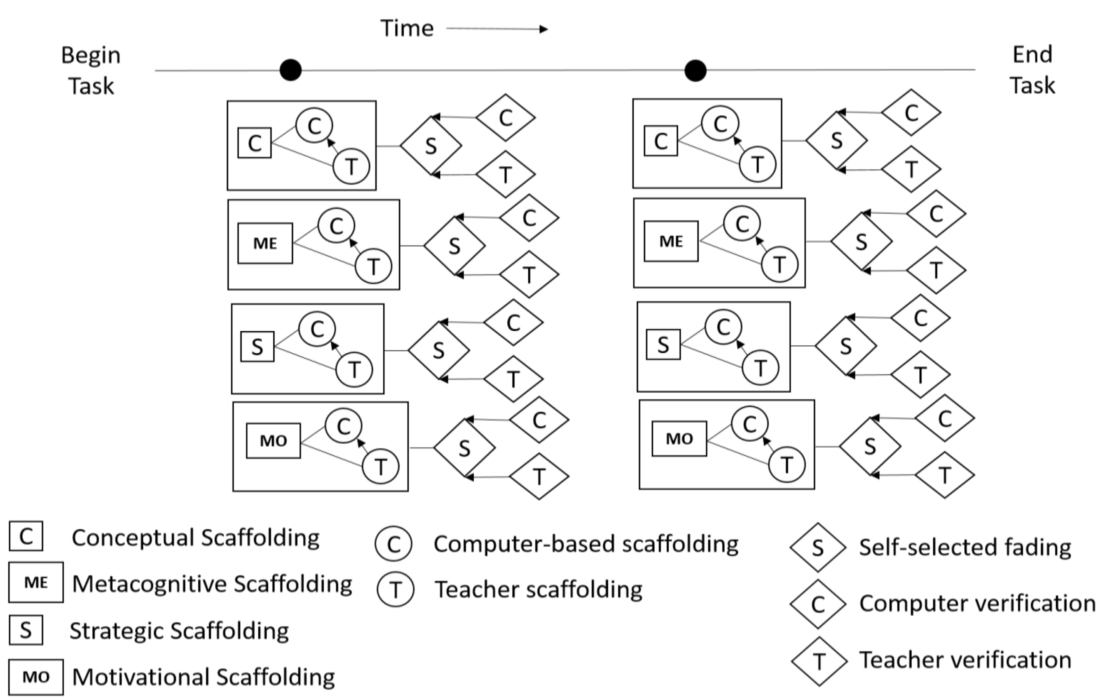


Figure 9. Fading systems to improve self-directed learning.

For example, computer systems can recognize students' current learning progress based on their learning stage, performance, and time and if computers judge that students' decision for fading is not the best of times, students will be provided reflective questions such as "Are you certain that you do not need help anymore?". In this case, computers play a supportive role in helping students' judgment about the decision of fading, but such questions can raise the likelihood that self-selected fading proceeds at the right time. In addition, it is possible for students to ignore computers' messages about their fading to finish the tasks as soon as possible. In this case, teachers can identify whether students stop receiving scaffolding with an exact understanding of content knowledge after a fixed time interval. So teachers can effectively control students' self-selected fading by providing questioning and prompts.

Adding supports. Studies of problem-based learning in which scaffolding is added are not numerous as in intelligent tutoring systems. In intelligent tutoring systems, adding is typically done by students themselves who push a hint button requesting more support (Girault & d'Ham, 2014; Rouinfar et al., 2014; Yin, Song, Tabata, Ogata, & Hwang, 2013). In addition, as supports are added, the characteristics of scaffolding can be changed from generic to context-specific to help students solve a specific learning issue at a certain step or process they experience the challenges (Koedinger & Aleven, 2007).

In intelligent tutoring systems, scaffolding can be added repeatedly until the correct answer is finally given (Koedinger & Aleven, 2007). However, there is no one right answer in PBL because the problems/tasks are ill-structured. Therefore, even though students keep asking for more scaffolds, scaffolding will just keep providing more specific guidance to solve the problem, not the right answer. This means that unlike fading, students are unlikely to make poor decisions about adding supports as they add supports only when they perceive it is necessary. This is because students can easily recognize that scaffolding never tells the right answer by trial and error, and if they want to finish learning quickly, they tended not to request more scaffolding. So in the case of adding support, the guidance by computers and teachers about students' decision like fading might not be required.

The strategy for adding supports in this paper is as follows (see Figure 10). First, by pushing the embedded button like "more help", students get immediate and more-specific scaffolding from the computer systems when the initial scaffolding with various sources and types cannot satisfy their needs in learning. This adding support systems have been utilized in the empirical research, and the positive effects on students' learning performance have been demonstrated (Kajamies et al., 2010; Mendicino, Razzaq, & Heffernan, 2009). Second, although the supports from computer systems are continuously added by students' request, if students cannot satisfy this help, they can ask other help to teachers directly. In this case as well, students push the button like "ask teachers", and then teachers can easily identify who wants more scaffolding through the network between students and teachers' computers. After teachers diagnose students' current learning status, they can add the suitable types and sources of scaffolding with more specific supports rather than the initial scaffolding. Teachers do not need to take care of all students; rather, the former can focus on students who request more help.

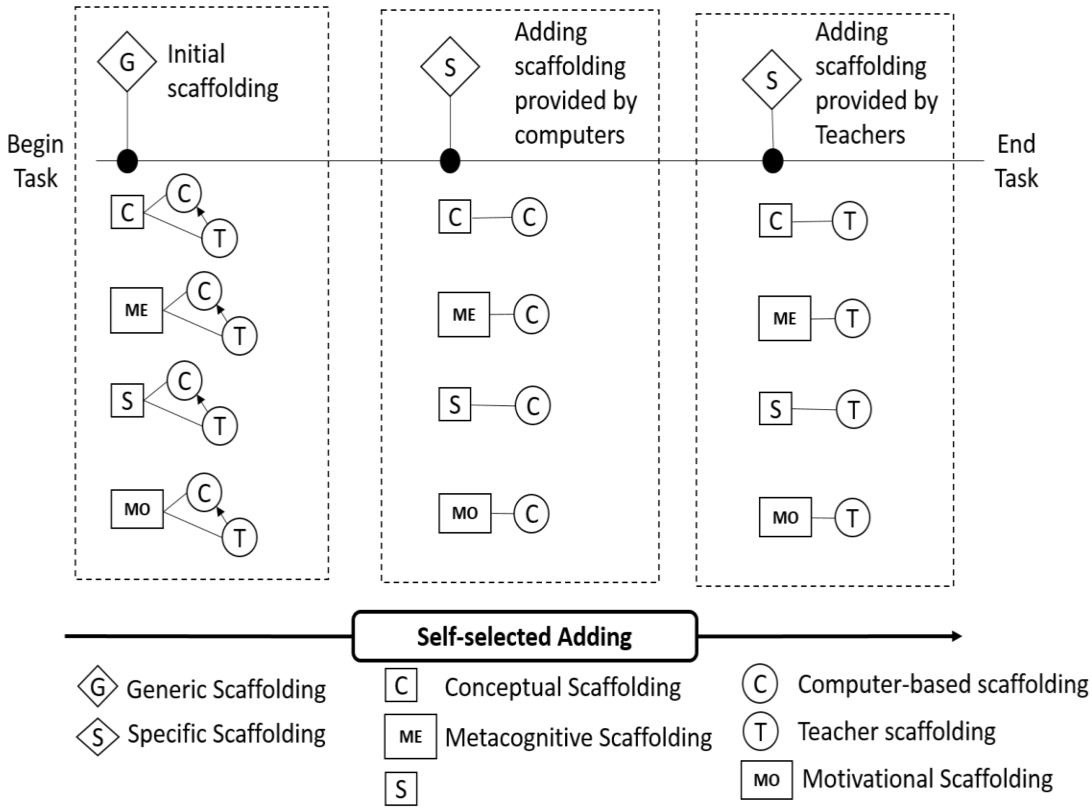


Figure 10. Adding systems to improve self-directed learning.

Therefore, this might be possible in the real classroom compared to the situation, in which teachers are in charge of scaffolding customization for all students.

Fading & adding supporting. Considering the above-mentioned roles of fading and adding supports, it is possible to design a singular scaffolding system that uses a combination of fading and adding scaffolding. Figure 11 suggests the fading & adding scaffolding system as combining the above-suggested fading and adding scaffolding design. The main point to emphasize in this fading & adding scaffolding system is that the choice of all fading & adding supports depends on students themselves. This is because Scaffolding Customization from self-selection enhances students' responsibility

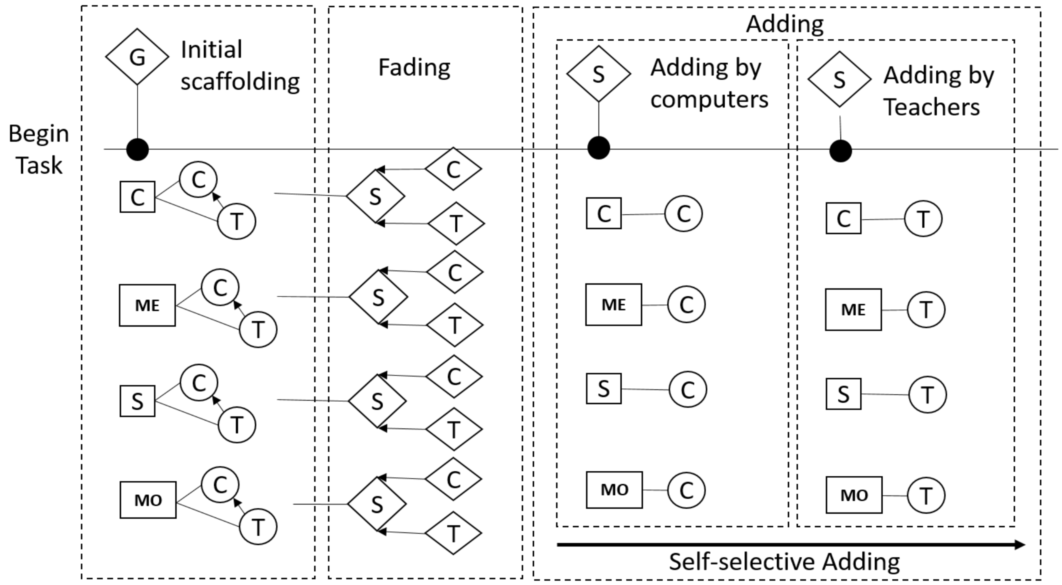


Figure 11. Fading & adding systems to improve self-directed learning.

and interests toward learning, resulting in improving the perception of optimal challenge, as self-determination theory explained (Loyens et al, 2008; Metcalf, 1999).

One example is "*Up, Up, & Away!!",* which consists of multiple scaffolding types (i.e., conceptual and strategic scaffolds), was used for improving students' scientific inquiry and learning performance in the context of Problem-based learning for science and technology education (Simons & Klein, 2007). In this study, the selection of fading & adding was determined by students themselves. Students could add various types of scaffolding with different nature according to their needs and learning contexts. And then, when they needed more specific supports about their learning issues, directly asking help to experts or teachers was also possible. Furthermore, students had a choice to reduce the scaffolding when they perceived it was not needed anymore. The results indicated that students who received scaffolding including adding & fading function (i.e., Scaffolding Optional Group) (*M* = 15.49) showed better performance (ES = 0.26) than those who got scaffolding without adding & fading function (i.e., Scaffolding Required Group) (*M* = 14.27). The adding system utilized in Simons & Klein's study was almost identical to the adding system suggested in this paper, but there is a difference of fading system in that the process to verify students' selection of fading did not exist in "*UP, UP, & Away!!*".

In summary, the above example shows the technical possibility of the suggested fading & adding systems although there are some differences in learning contexts and specific components of fading & adding scaffolding.

Collaborative Learning in Problem-based Learning

Students' challenge. In PBL, collaborative learning makes the problem-solving process more effective and efficient (Barrows, 1996). By dividing roles of the process between students, many diverse problem-solving methods can be created. Students can perform the tasks while watching the execution process of other students and expand their thinking related to problem-solving (Belland, 2014). This can lead to students' reflection on their own problem-solving process and strategy. Therefore, students can initiatively engage in the learning activities by collaborative learning, resulting in an improvement of students' autonomy and relatedness as the important factors to perceive optimal challenge (Benson, 1996; Du, Ge, & Xu, 2015; Fan & others, 2015).

However, collaborative learning often suffers from issues caused by group composition. Groups often include one or two students who show a passive attitude to learning due to a lack of motivation, learning goal, and ability (Kaufman et al., 1999). At first, this type of student makes a superficial attempt to engage in the group activity, but shortly afterward, they negatively affect group members' collaboration due to disturbance and off-task behavior. In the opposite case, there might be a student who has more advanced knowledge and leadership than other group members, but the problem is that this student accidently or deliberately tends to ignore the opinions of group members who were regarded as the obstructers from his/her perspectives. Furthermore, a progression to next step in PBL can be delayed by other students' slow learning pace, and it, in turn, decreases the level of immersion in learning. This type of student prefers to learn alone due to the efficiency of learning (Cela et al., 2015). The tasks in PBL, which require active collaborative learning, might be not optimally challenging from this student' perspective. Unequal participation and a lack of discussion in the group, which consists of students with different abilities and learning paces, make it hard for students to psychologically experience optimal challenge if there are few proper supports to balance the difference abilities between group members (see Figure 12).

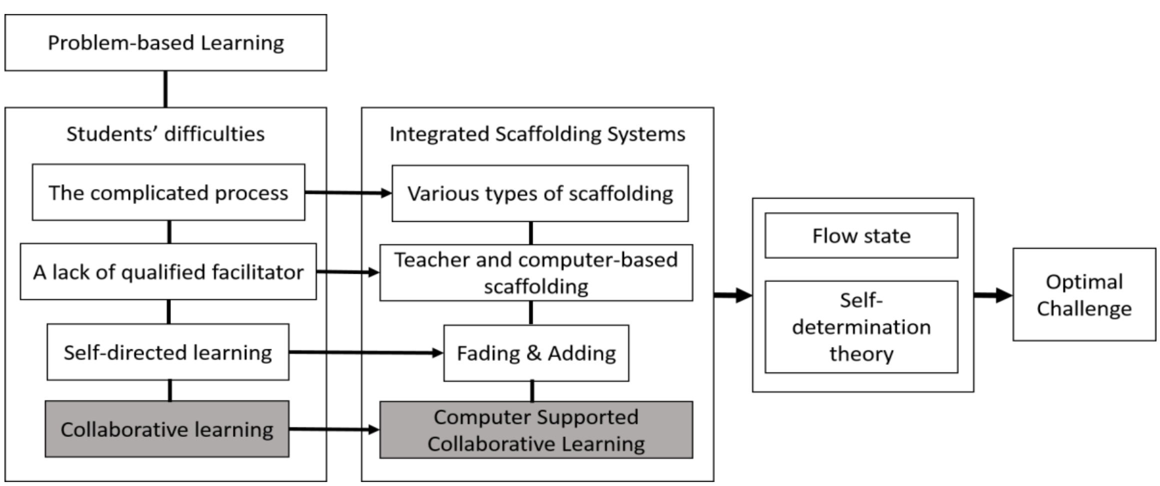


Figure 12. Computer supported collaborative learning.

Suggested scaffolding. In PBL, group work is critical to complement individual students' lack of skills by obtaining more reasonable solutions and further information from peers (Hommes et al., 2014). Therefore, collaborative learning systems, which enable the exchange of information through close interaction between learners, should be established to overcome the individual differences in PBL (Savery, 2015). To address this, research related to Computer Supported Collaborative Learning (CSCL) has been extensively carried out. Learners create learning communities in the CSCL environment and they show the following cognitive growth through the experience of forming and developing knowledge within the groups (Okada, 2005). First, learners can develop the skills to pursue and construct knowledge. Second, learners can improve the communication skills through the arguments among members. Third, learners can experience higher-order skills such as critical thinking, reflective thinking, and creative thinking. In this regard, many studies have utilized CSCL in PBL and demonstrated the effects of CSCL on enhancing the group activities in PBL (Hmelo-Silver & Eberbach, 2012; Koschmann, Kelson, Feltovich, & Barrows, 1996; Lu, Lajoie, & Wiseman, 2010). However, CSCL has yet not fully considered the different patterns of behavior seen in active and passive students (Kwon, Liu, & Johnson, 2014). Passive or active nature of students has a strong influence on the success in CSCL. Generally, students who display a passive attitude toward their learning lack content knowledge, learning skills, and motivation (Benware & Deci, 1984; Huang & Chiu, 2015). If CSCL just focuses on the development of collaboration skills without consideration of individual supports, which help the passive students actively engage in learning, it can be just superficial group interaction. In this sense, the results of meta-analysis, which analyzed and synthesized the effects of CSCL from 175 articles, indicated that CSCL had a large effect (d = 0.63) on enhancing collaborative skills, but a small effect (d = 0.26) on improving students' domain-specific knowledge in the context of K-12 education (Vogel, Wecker, Kollar, & Fischer, 2016). This is because of a lack of content-related individual supports in CSCL (Kollar, Ufer, Reichersdorfer, Vogel, Fischer, & Reiss, 2014). To address this issue, this paper suggests CSCL considering individual works based on the idea retrieved from Team Assisted Individualization (TAI) suggested by Slavin, Madden, & Leavey (1984). TAI assigns the different roles considering the different level of students' ability to each student in the group, and each student enhances the motivation by conducting the learning task in accordance with the individual's ability discriminatorily. In other words, TAI can overcome the learning differences between students in the group work. Moreover, the advanced CSCL provides the immediate scaffolding to students in order to move across individual learning and collaborative learning in PBL (Jeong & Hmelo-Silver, 2016). Figure 13 shows the advanced CSCL this paper suggested.

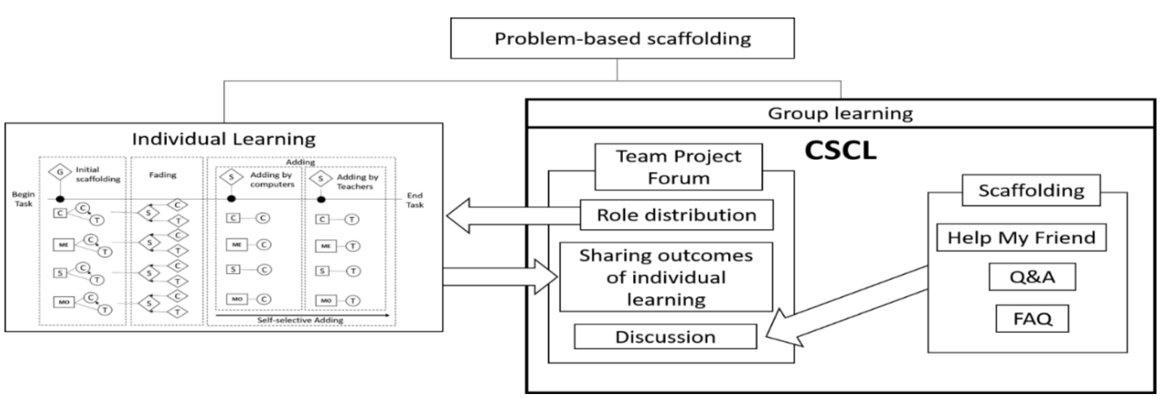


Figure 13. Collaborative learning system in PBL.

The above model explains the collaborative learning systems, composed of individual and collaborative learning. At the beginning of the unit, the proper role and sub-tasks are assigned to each student through discussion between group members and the advice of teachers. Students proceed in their individual learning according to their learning ability and pace. The difficulties occurring during individual learning can be addressed by the several types and sources of scaffolding and the fading/adding supports of scaffolding, which were described in the previous sections. The learning outcomes from each student' research can be uploaded into the team project forum. Then, the students come back together into their Team Project Forum to review each other's results. They come to a consensus about inconsistent evidence and claims for solutions through discussion, and their conclusion becomes the final group claim. In addition to scaffolding in individual learning, the group learning needs scaffolding to enhance group interaction, evaluate the resources each student gathered, and to draw the consistent conclusion. 'Help My Friend', 'Q&A', and 'FAQ' play a role in scaffolding in the suggested CSCL. Each student has the differences in the degree of prior knowledge as well as interests and attitude about current learning. In other words, the role of students as learners with excellent learning skills or as an assistant to help the peers can vary. 'Help My Friend' enables peer scaffolding. A student who requires help in CSCL is connected with peers who have similar levels of individual learning and current learning pace. Figure 14 shows how to provide peer scaffolding among students with similar ability. The grey block indicates students' current steps in PBL. The solid line means possible peer scaffolds between students who have the similar abilities (e.g., A and D, B and C, C and D).

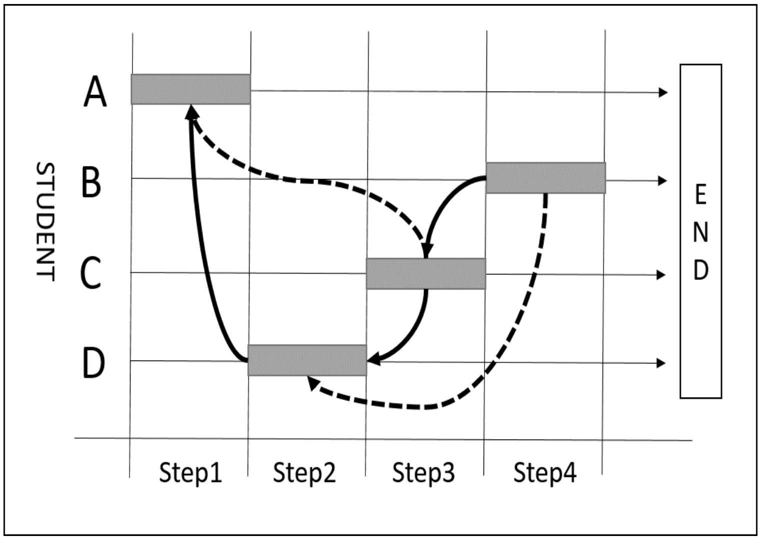


Figure 14. Peer scaffolding in CSCL.

In addition, it is possible that peer scaffolding between similar-ability students does not work well. If this case, supportive peer scaffolding (the dotted line) from a little bit advanced student can be utilized.

However, the network between students who have a big gap in terms of learning pace and abilities is not provided. This supports Csikszentmihalyi (1996)'s claim that collaborative learning among students with similar ability improves the intrinsic motivation by raising their interests and it leads to students' perception of a great challenge. The reason of connection with students with similar ability and pace is that they can better understand each other's difficulties by sharing their experience in solving similar issues. One issue on this system is that the peer scaffolding between students with low level of ability might be superficial and shallow, resulting in intensifying students 'confusion. In this sense, for the effective peer scaffolding the guideline to explain how and when peer scaffolding should be provided is required. Table 2 shows guidelines for the use of peer scaffolding to elicit the perception of optimal challenge.

Table 2

Guidelines for Peer Scaffolding that Promotes the Perception of Optimal Challenge

Guideline of Peer Scaffolding	The effect of peer scaffolding on perception of optimal challenge
1a. Describe tasks by providing narratives of peers that show the accomplishment of other students with similar problems (Belland et al., 2013). 1b. Enable students to search and access peers' evaluation about previous works (Saavedra & Kwun, 1993; Trivedi, Kar, & Patterson-McNeill, 2003).	Peer scaffolding allows students to identify the difficulty of tasks, and help them perceive tasks as manageable.
2a. Embed discussion between peers to enhance motivation (Kear, 2004; Slavin, 1987; Suh, Kim, & Kim, 2010) 2b. Enable students to improve motivation through cooperative learning including peer interaction (Slavin, 1987) 2c. Provide immediate peer feedback to students for maintaining motivation (Carrico & Riemer, 2011) 2d. Assign suitable roles according to ability (Soller, Goodman, Linton, & Gaimari, 1998)	Peer scaffolding can motivate students toward their learning, and students can be immersed in their learning
3. Embed peer-questioning to help students to understand current their ability (Choi, Land, & Turgeon, 2005)	Peer scaffolding can instill self-confidence about the achievement of tasks, and it can make students to successfully accomplish their tasks.
4. Enable students to experience the internalization process of learning through peers learning (Damon, 1984)	Students can experience the internalization process through the peer scaffolding, and this can lead them self-determination as an essential factor to perceive optimal challenge.

FAQ provides immediate scaffolding without waiting for the time period by posting the answers to the anticipated questions on the board, and it allows individual learning. On the other hand, it is difficult to anticipate the questions learners want to ask. If students are not satisfied with the scaffolding provided by peers or computer systems, they can directly request the additional help to teachers through Q&A board. Teachers who are monitoring students' learning status can provide more detailed and just-in-time supports to students independently.

Limitation

Several limitations to this approach have been identified and require further research. Little is known about the effectiveness of the combination of timing, types, sources, and customization of scaffolding. In addition, the complicated scaffolding system this paper suggests can cause cognitive overload (Mayer & Moreno, 2003). Therefore, more empirical research to address the above issues is required.

Continuous monitoring of student progress may become burdensome to the scaffolding provider who is less acquainted with the many sources of scaffolding types. Making decisions about timing, type, levels and sources of scaffolding imply a variety of options about which a teacher needs to be informed and prepared. Algorithms upon which computer-based support of student scaffolding decisions may be difficult to design.

Discussion

When PBL tasks are perceived by students as optimally challenging, intrinsic motivation can be enhanced (Mandigo & Holt, 2006) through satisfaction of the following psychological needs: a) autonomy, b) competence, and c) relatedness (Deci & Ryan, 2002). This, in turn, leads to students' active engagement in learning and their experience in the flow status (Csikszentmihalyi, 2014). PBL provides the learning environment to experience these psychological needs in that students take responsibility for their learning, conduct their research with peers, and experience success in tackling the rigor of ill-structured problems by themselves (Savery, 2015). However, the complicated problem-solving process and a lack of self-directed learning and cooperative learning make it difficult for K-12 students to experience optimal challenge by accomplishing the given tasks in PBL (Wijnia et al., 2015). In order to address the above-mentioned learning issues, this paper suggests Learner-centered Scaffolding Systems (LSS), which utilize the multiple types and sources of scaffolding, fading & adding function, and the advanced CSCL considering students' individual learning together. To be successful in PBL, a student needs to handle all the kinds of rigor brought on by deficiencies in knowledge or skills (Belland, 2016). Many scaffolds have been suggested and implemented to support students' difficulties in problem-centered instructional models, but their roles were limited to address only one or few certain area of difficulties such as domain knowledge, learning strategies, and collaborative learning. In order to solve this issue, distributed scaffolding suggested by Puntambekar & Kolodner (2005) is consistent with the intended purpose of multiple types of scaffolding in that various types of scaffolding are provided according to each student's current needs, understanding, interest, and motivation. However, the limitation of Puntambekar & Kolodner (2005)'s study is that they did not mention about how scaffolding can be effectively delivered to students who have different levels of abilities. In this sense, LSS suggested by this paper can enhance students' perception of optimal challenge by addressing students' all kinds of difficulties in PBL and enhancing students' intrinsic motivation toward learning.

As LSS supports students' diverse difficulties occurred during PBL with various types of scaffolding- conceptual, metacognitive, strategic, and motivational scaffolding, it can help students handle difficulties in many contexts and regardless of students' levels (Hannafin et al., 1999), and lead to improvement of students' motivation and confidence toward the accomplishment of tasks (Gormley, Colella, & Shell, 2012). Moreover, the effective delivery of several types of scaffolding can be operated by the combination of teachers and computer systems. The role of computer-based scaffolding is to provide a generic and immediate response to the broad range of student needs that occur during learning and teacher scaffolding can provide more advanced and sophisticated supports to students (Belland, 2014). In this system, teachers do not need to monitor all students' learning status, and it is possible for one teacher to handle 25+ students in the classroom. In other words, the several types of scaffolding can be delivered to students more efficiently and effectively as addressing students' needs immediately and in detail. This allows students to learn how well they performed the activities, and what they can do to improve.

A lack of students' skills regarding self-directed learning can be addressed through their fading/adding of scaffolding by their own selection (Collins et al., 1989; Van de Pol et al., 2010). Fading by self-selection can allow students to take responsibility for their learning, and it can enhance students' motivation, self-determination and confidence (Savery, 2006). Moreover, teachers and computers support students' decision of fading, and a rash or wrong decision on scaffolding customization from students can be prevented. Adding supports by self-selection can also improve students' self-directed learning skill as changing the nature of scaffolding from generic to context-specific according to their own decision (Koedinger & Aleven, 2007; Koedinger & Corbett, 2006). Students' requesting of adding scaffolds means their passion and expectation for success, and it leads to students' perception of optimal challenge. Another important activity in PBL is collaborative learning, which allows students to arrive at more reasonable and valuable solutions by sharing their experience, information, and learning strategy (Barrows, 1994; Hmelo-Silver, 2004). However, K-12 students have diverse learning skills, background knowledge, and motivation, and the composition of group members with unbalanced abilities might cause the reduction of interests and confidence (Moos & Azevedo, 2009). Therefore, CSCL, as suggested in this paper, considers the individual works according to each students' ability and the utilization of peer scaffolding between students with similar learning abilities and pace. Within this system, group members figure out that whole group cannot proceed their learning if anyone does not finish the tasks assigned to each group member. Therefore, they participate in individual learning and collaborative learning as well as peer scaffolding to support students with low ability and slow pace. This can enhance students' responsibility and autonomy for successful learning (Du et al., 2015; Miller & Hadwin, 2015). The proposed LSS design may seem too complex, but recently, some intelligent tutoring systems have partially adopted the above suggested scaffolding (Beal, Arroyo, Cohen, Woolf, & Beal, 2010; Woo et al., 2006).

Conclusion and Implication

Learner-centered Scaffolding Systems (LSS) suggested in this paper can enhance students' experience in autonomy and competence by providing multiple types of scaffolding in accordance with student' different needs and difficulties in PBL as well as by effectively and efficient delivering these scaffolds through teachers and computer systems. In addition, students can control the nature and frequency of scaffolding by themselves according to their needs and ability, and it plays a role in improving their self-directed learning skills. Last, peer scaffolding between students with similar abilities satisfies students' needs for relatedness. Students' autonomy, competence, and relatedness, which were improved by LSS, directly connected students' immersion and intrinsic motivation toward their learning. Through all supports from LSS students can improve the perception of optimal challenge in the given tasks in PBL.

There are many positive implications when using LSS scaffolding to achieve optimal challenge. Teachers are supported in their attempt to provide help for all students and can be assured that struggling students receive the needed help (Tabak, 2004). Self-directed learning in PBL can be amplified when students control not only who they turn to for help but also the selection of the type and quantity of help they need to confront by challenges beyond their abilities (Dahlgren & Dahlgren, 2002; Hmelo-Silver & Barrows, 2006). As a consequence, student confidence to take on the ill-structured nature of PBL will increase and student problem-solving abilities will grow (Guglielmino, 2008; Lefever-Davis & Pearman, 2015).

CHAPTER III

EFFECTIVENESS OF COMPUTER-BASED SCAFFOLDING IN THE CONTEXT OF PROBLEM-BASED LEARNING FOR STEM EDUCATION: BAYESIAN META-ANALYSIS

Abstract

The effectiveness of computer-based scaffolding has been demonstrated through traditional meta-analyses. However, traditional meta-analyses suffer from small-study effects and a lack of studies covering certain characteristics. This research determines the effectiveness of computer-based scaffolding in the context of problem-based learning for STEM education through Bayesian Meta-Analysis. Specifically, several types of prior distribution information inform Bayesian simulations of studies, and this generates accurate effect size estimates of six moderators related to the characteristics of computer-based scaffolding and the context of scaffolding utilization. The results of BMA indicated that computer-based scaffolding significantly impacted (g = 0.385) cognitive outcomes in problem-based learning in STEM education. Moreover, according to the characteristics and the context of use of scaffolding, the effects of computer-based scaffolding varied with a range of small to moderate values. The result of BMA contributes to an enhanced understanding of the effect of computer-based scaffolding and can inform guidelines about which types and strategies of scaffolding should be used in a certain timing and situation.

Keywords: Computer-based Scaffolding, Problem-based Learning, STEM education, Bayesian Meta-analysis

Introduction

The Next Generation Science Standards promote the use of problem-based learning (PBL), which requires that students construct knowledge to devise solutions to ill-structured, authentic problems (Achieve, 2013). Central to student success in such approaches is scaffolding – dynamic support that helps students meaningfully engage in and gain skill at tasks that are beyond their current abilities (Belland, 2014; Hmelo-Silver, Duncan, & Chinn, 2007). When originally defined, instructional scaffolding was delivered one-to-one by a teacher. But it is difficult for one teacher to present immediate support to every student when classrooms contain 20-30 students (Wu, 2010). In this sense, researchers began to think about the utilization how scaffolding could be packaged in the form of computer-based tools (Hawkins & Pea, 1987). Computer-based scaffolding has been utilized in Science, Technology, Engineering, Mathematics (STEM) education in the context of PBL, and many studies have demonstrated the effect of computer-based scaffolding on students' conceptual knowledge and higher order skills. However, it is difficult to generalize from the results of individual studies without the systematic synthesis methods (e.g., meta-analysis) due to different educational population in particular contexts.

Meta-analysis is a statistical method that combines results from multiple individual studies that have the same or similar research questions (Hedges & Olkin, 2014). Meta-analyses are often seen as more thorough and accurate than just reviewing all related studies in that they can correct for sampling errors and measurement errors between studies. There have been many meta-analyses to integrate the effectiveness of computer-based scaffolding (Azevedo & Bernard, 1995; Belland, Walker, Kim, & Lefler, in press; Ma, Adesope, Nesbit, & Liu, 2014), but few focused specifically on scaffolding in the context of PBL. PBL has totally different learning process and the tasks characteristics (e.g., ill-structured and authentic tasks) comparing to traditional teacher-led instruction, and it requires students' different abilities (e.g., higher-order thinking skills and self-directed learning skills) to accomplish the given tasks (Savery, 2015). Therefore, the role and effectiveness of computer-based scaffolding can be different in PBL, leading the different results from the existing meta-analyses, which reported the positive impacts of computer-based scaffolding on students' cognitive outcomes in any learning contexts. In addition, there have been not a large number of studies utilizing the computer-based scaffolding in PBL. This makes it difficult to conduct meta-analysis in terms of the effectiveness of computer-based scaffolding characteristics and its contexts. Moreover, traditional meta-analysis might have the issue of publication bias, which is affected by small sample size. To address these issues, this study conducted Bayesian meta-analysis. Bayesian approach directly estimates a population parameter by the combination of prior knowledge regarding an effectiveness of interventions and computational techniques (e.g., simulations by Markov Chain Monte Carlo; Hartung, Knapp, & Sinha, 2011). In other words, in Bayesian model, the parameters are random/uncertain and the data from samples is fixed and only used to construct the initial likelihood function (Spiegelhalter, Abrams, & Myles, 2004). Therefore, contrary to the frequentist approach in traditional meta-analysis, the results from Bayesian approach do not suffer from publication bias and a small number of the observed data points because the role of samples is not to estimate a population parameter (Hahn, 2014).

Consequently, this study aims to determine and generalize the effectiveness of computer-based scaffolding utilized in PBL in terms of several characteristics of computer-based scaffolding and its contexts through Bayesian meta-analysis.

Computer-based Scaffolding in Problem-based Learning

Problem-based learning (PBL) is a learner-centered instructional approach that aims to improve students' content knowledge and problem-solving skills through engagement with authentic and ill-structured problems, which have no single answer (Hmelo-Silver, 2004; Kolodner et al., 2003; Thistlethwaite et al., 2012). Students acquire new knowledge by identification of knowledge gaps between their current level of knowledge and the level of knowledge it would take them to address the given problem (Barrows, 1996). To accomplish the given tasks in PBL, students need diverse skills including advanced problem-solving skills, critical thinking, and collaborative learning skills (Gallagher, Sher, Stepien, & Workman, 1995). However, as for students who are familiar with teacher-led instruction, they can experience different learning issues occurring in PBL due to different levels of background knowledge, learning skills, and motivation. Scaffolding has been utilized to make the tasks in PBL more manageable and accessible (Hmelo-Silver et al., 2007) and to help students improve deep content knowledge and higher order thinking skills (Belland, Glazewski, & Richardson, 2011). Computer-based scaffolding, especially, has had positive impacts on students' cognitive learning outcomes. For example, students can be invited to consider the complexity that is integral to the target skill and spared the burden of addressing complexity that is not (Reiser, 2004) through computer-based hints (Leemkuil & de Jong, 2012; Li, 2001; Schrader & Bastiaens, 2012), visualization (Cuevas, Fiore, & Oser, 2002; Kumar, 2005; Linn, Lee, Tinker, Husic, & Chiu, 2006), question prompts (Hmelo-Silver & Day, 1999; Kramarski & Gutman, 2006), and concept mapping (Puntambekar, Stylianou, & Hübscher, 2003). In addition, computer-based scaffolding can improve students' interest and motivation towards their learning (Clarebout & Elen, 2006).

Meta-analyses Related to Computer-based Scaffolding

Computer-based scaffolding has been found to positively impact many variables across many studies. However, generalizing such results is difficult because the learning environment, population, and experimental condition vary across the studies. Therefore, some scholars tried to combine the results and synthesize information from multiple individual studies through meta-analysis. Belland, Walker, Kim, and Lefler (in press) conducted a traditional meta-analysis to determine the influence of computer-based scaffolding in the context of problem-centered instructions for STEM education. The overall effect size of scaffolding was $g = 0.46$ (Belland et al., in press). This result indicated that computer-based scaffolding can help students learn effectively in problem-centered instruction including problem-based learning for STEM education. In addition, in the case of the conventional instruction, not of problem-centered instructional models, meta-analysis indicated that computer-based scaffolding including intelligent tutoring systems positively impacted on students' learning ($g = 0.66$) regardless of instructor's effects, study types, and region (Kulick & Fletcher, 2016). However, there have been few studies to investigate the effectiveness of computer-based scaffolding in the context of problem-based learning.

Issues of Traditional Meta-analysis

Meta-analyses offer much more in the way of systematicity than traditional research reviews, but some scholars (Biondi-Zoccai, Agostoni, Abbate, D'Ascenzo, & Modena, 2012; Greco, Zangrillo, Biondi-Zoccai, & Landoni, 2013; Koricheva, Gurevitch, & Mengersen, 2013) noted two potential pitfalls (i.e. publication bias by small-study effect and small number of included studies) that can occur during meta-analysis. One issue is related to small-study effects. In meta-analyses, the effect size is estimated based on the observations of previous individual studies. For meta-analyses these observations should be standardized, but multiple errors can occur because of the size of studies involved. Small studies tend to report larger effect sizes than large studies, and the effect sizes from studies with small sample sizes (i.e., $n < 10$) can be biased (Hedges, 1986). This in turn can lead meta-analyses with publication bias, which is more likely to publish the larger effect size than the small effect size. For this reason, some scholars concluded that if both small-study effects and large study effects are included in one data set, researchers should focus on analyzing only large study effects (Biondi-Zoccai et al., 2012; Greco et al., 2013; Hedges, 1986; Koricheva et al., 2013).

Another issue is that in traditional meta-analysis, there is no method to include a certain variable if the number of studies handling a variable is too small. There has been a debate on the minimum number of studies, which should be included in meta-analysis (Guolo & Varin,205). In theory, one can conduct meta-analysis with just two studies

(Valentine, Pigott, & Rothstein, 2010), but in this case, the statistical power is largely reduced. In one study (Valentine et al, 2010), which investigated the difference of statistical power in meta-analysis according to the included number of studies, the range of power in meta-analysis with 10 studies was not beyond 0.2 (random effect model with large heterogeneity), 0.4 (random effect with small heterogeneity), and 0.5 (fixed effect model). However, in educational field, especially PBL, it might be difficult to have a large number of studies, which can be categorized together into the same intervention (i.e., computer-based scaffolding), due to different education population and level, learning environment, and outcomes. This makes meta-analyses in educational field harder to generate the reliable and validated results (Ahn, Ames, & Myers, 2012).

Considering the above-mentioned issues of meta-analysis, it might be necessary to consider an alternative methodology to address the publication bias by small-study effects and a small number of the included studies. This study suggests Bayesian approach to conduct meta-analysis for determining the effect size of computer-based scaffolding in the context of problem-based learning. The explanation of Bayesian meta-analysis will be specified in the next section.

Bayesian Meta-analysis

An alternative to address the issue of traditional meta-analysis is to use a Bayesian approach, which assumes that all parameters come from a superpopulation with its own parameters (Hartung, Knapp, & Sinha, 2011; Higgins et al., 2009). This approach relies on (a) generating a prior distribution (ρ (Θ)) utilizing data from pre-collected studies that should not be included in Bayesian meta-analysis, (b) estimating the likelihood that the prior distribution is valid based on the observed data (ρ(data|Θ)), and (c) generating a posterior distribution, which can be calculated by the Bayesian law of probability (ρ(Θ|data)). In short, this approach can provide a more accurate estimate of a treatment effect by adding another component of variability - the prior distribution (Schmid & Mengersen, 2013). Prior distribution is defined as a distribution that articulates researchers' beliefs or the results from previous studies about parameters prior to the collection of new data (Raudenbush & Bryk, 2002). Prior distributions play a role in summarizing the evidence and determining evidential uncertainty (Spiegelhalter, Abrams, & Myles, 2004). In the Bayesian model, μ (weighted mean effect size), τ (standard deviation of the between-study variance), and β (study-level covariates) of prior distributions can be important factors in estimating prior distributions (Findley, 2011; Sutton & Abrams, 2001).

Typically, the prior distribution can be divided into two types (i.e., informative and non-informative prior distribution) according to whether prior information (i.e., μ, β, and τ) about the research interests exists or not. When prior information is not available, the Bayesian approach commonly uses non-informative prior distribution. The posterior distribution can be different according to how the between-study variance (τ^2) in the prior distribution is set up (see Table 1). It might be difficult to specify τ^2 due to a lack of information for parameters; therefore, it is important to consider all possible τ^2 (i.e., maximum values of τ^2 and minimum values of τ^2) in non-informative prior distribution. As seen in Table 1, the purpose of reference prior distribution is to maximize the divergence between the variances of studies, and it can generate maximum effects of

Table 1

Reference as Non-informative Prior Distributions for τ^2 (Spiegelhalter et al., 2004)

Reference	Distribution for τ^2	Characteristics
DuMouchel prior for τ^2	$\tau_0^2 = \frac{S_0}{9}$ and $\tau_0^2 = 9S_0$	• a highly-dispersed prior distribution for τ^2 • values of τ^2 to be near 0 • Protection of highly skew toward large values of τ^2
Uniform Prior for τ^2	$\tau^2 \sim Uniform(0,1000)$	• Large value of τ^2
Inverse Gamma Prior on τ^2	$\frac{1}{\tau^2} \sim$ Gamma(.001, .001)	• Greater weight to values of τ near 0

newly added data on the posterior distribution (Sun & Ye, 1995). After assuming all kinds of variance of studies using reference prior distribution, one can identify the most suitable prior distribution model by Deviance Information Criteria (DIC) as one of the fit statistics (Spiegelhalter, Best, Carlin, & Van Der Linde, 2002).

Research Questions

The purpose of this study is to determine the estimates of effect sizes of computer-based scaffolding in the context of PBL through Bayesian meta-analysis by addressing the following research questions.

1) How does computer-based scaffolding affect students' cognitive learning outcomes in the context of problem-based learning for STEM education?
2) How does the effectiveness of computer-based scaffolding vary according to scaffolding intervention?

3) How does the effectiveness of computer-based scaffolding vary according to scaffolding customization and its methods?
4) How does the effectiveness of computer-based scaffolding vary according to the higher-order skill it is intended to enhance?
5) How does the effectiveness of computer-based scaffolding vary according to scaffolding forms?
6) How does the effectiveness of computer-based scaffolding vary according to discipline?

Method

Search Process

Education Source, PsycInfo, Digital dissertation, CiteSeer, ERIC, and Google scholar were searched using the search terms “computer-based scaffolding, scaffold, scaffolding”, “intelligent tutoring system”, “computer-based supports”, “cognitive tutors”, “pedagogical agents”, “Science, Technology, Engineering, and Mathematics," and subcategories of higher-order thinking skills.

Inclusion Criteria

The following inclusion criteria were used: Studies needed to a) be published from January 1, 1990 and December 31, 2015, b) present sufficient information to conduct Bayesian meta-analysis (statistical results revealing the difference between treatments and control group, number of participants, study design), c) be conducted in the context of Problem-based learning within STEM education, d) clearly reveal which types of scaffolding they used, and e) address higher-order thinking skills as the intended outcome of the scaffold itself. I found a total of 21 articles and 47 outcomes.

Moderators for Meta-Analysis

Scaffolding intervention. Conceptual scaffolding provides students expert hints, concept mapping and/or tools to engage in concept mapping, and visualization depicting concepts to help them identify what to consider when solving the problem (Hannafin, Land, & Oliver, 1999). Strategic scaffolding helps students identify, find, evaluate information for problem-solving and guide a suitable approach to solve the problems (Hannafin et al., 1999). Conceptual scaffolding can be distinguished from strategic scaffolding in that conceptual scaffolding helps students consider the tasks from different angles through the reorganization and connection of evidence, on the other hand, strategic scaffolding tells students how to use the evidence for problem-solving (Saye & Brush, 2002). Metacognitive scaffolding allows students to reflect on their learning process and encourages students to consider possible problem solutions (Hannafin et al., 1999). Motivational scaffolding aims at enhancing students' interest, confidence, and collaboration (Jonassen, 1999a; Tuckman & Schouwenburg, 2004).

Higher order thinking skills. Scaffolding is often designed to enhance higher-order thinking skills (Aleven & Koedinger, 2002; Azevedo, 2005; Quintana, Zhang, & Krajcik, 2005). The definition of higher-order thinking and its sub-categories differ according to different scholars. Higher-order thinking can be defined as "challenge and expanded use of the mind" (Newmann, 1991, p.325) and students can enhance higher-order thinking skills through active participation in such activities as making hypotheses, gathering evidence, and generating arguments (Lewis & Smith, 1993). In addition, many scholars categorized higher-order skill types (See Table 2).

As seen in Table 2, higher-order skills can be categorized into several types, but it has been difficult to achieve a consensus among scholars about the types. However, the above-mentioned types of higher order thinking skills can be traced to Bloom's taxonomy in that these categorizations can be explained as a derivative of Bloom's taxonomy (Brookhart, 2010; King, Goodson, Rohan, 1998; Lipman, 2003; Meyers, 1986; Miller, Nentl, & Zietlow, 2014; Nemann, 1991; Ormrod, 2013; Woolever & Scott, 1988).

Table 2

Categorization of Higher Order Thinking Skills

Authors	**The categories of higher-order thinking skills**	**Authors**	**The categories of higher-order thinking skills**
Meyers (1986)	•Critical thinking •Creative thinking	Ormrod (2013)	• Analysis • Evaluation • Creation (as the "top end" of Bloom's taxonomy)
Newmann (1991)	•Critical thinking •Creative thinking •Reasoning •Problem-solving •Decision-making	Brookhart (2010)	• Analysis, Evaluation, and Creation (as the "top end" of Bloom's taxonomy) • Logical thinking • Judgment and critical thinking
Woolever & Scott (1988)	•Critical thinking •Creative thinking •Problem-solving •Decision-making	King, Goodson, & Rohani (1998)	• Critical thinking • Logical thinking • Reflective thinking • Metacognitive thinking • Creative thinking
Lipman (2003)	•Critical thinking •Creative thinking •Caring thinking		

According to Bloom's taxonomy (1956a), higher order thinking is the stage beyond the understanding and lower level application of knowledge. Therefore, analyzing, synthesizing, and evaluating can be classified as higher-order skills. Analysis means the ability to identify the components of information and ideas, and to establish the relations between elements (Lord & Baviskar, 2007). Synthesis refers to recognition of the patterns of components and the formation of a new whole through creativity. Through this ability learners can formulate a hypothesis or propose alternatives (Anderson, Krathwohl, & Bloom, 2001). Defined as the ability to judge the value of material based on definite criteria, evaluation allows learners to judge the value of data and experimental results and justify conclusions (Krathwohl, 2002). Based on the above illustrative phrases, critical thinking and logical thinking can be combined to form the critical thinking category of ‘Analysis’ and creative thinking and reflective thinking can be combined to form the critical thinking category of ‘Synthesis’, and problem-solving skills and decision-making can be combined to form the critical thinking category of ‘Evaluation’ (Bloom, 1956; Hershkowitz, Schwarz, & Dreyfus, 2001).

Therefore, higher-order thinking skills can be defined as cognitive skills equivalent to the levels of the analysis, synthesis, and evaluation in Bloom’s Taxonomy, and so in this study, the categorization for intended outcomes can be analysis, synthesis, and evaluation as the variation of higher-order skills.

Scaffolding customization. By effectively controlling the timing and degree of scaffolding, students reach the final learning goal by their own learning strategies and processes (Collins, Brown, & Newman, 1989). In this sense, scaffolding should be customized based on a dynamic assessment of students' current abilities (Belland, 2014). Intelligent Tutoring Systems (ITS) provide immediate and individualized help to students by ongoing-diagnosis (Crowley et al., 2007). If an ITS judges that students might be able to reach the desired goal without scaffolding by tracking of students' performance, scaffolding can be faded (Beal, Arroyo, Cohen, Woolf, & Beal, 2010). On the other hand, if students continue to struggle excessively, greater quantities and intensities of scaffolding can be requested through the use of a hint button (Chang, Sung, & Chen, 2001). As explained above, in ITS that can monitor students' ability, scaffolding fading is often performance-adapted and adding supports self-selected. In addition to the bases of performance and self-selection, scaffolding customization can also be based on fixed time intervals, which means a predetermined number of events or fixed time. However, according to Belland et al (in press)'s meta-analysis, 65% of studies did not have any scaffolding customization. Moreover, Lin, Hsu, Lin, Changlai, Yang, & Lai (2012) also pointed out a lack of a number of studies adopting fading function (9.3%) in a review of 43 scaffolding-related articles. This means that while many scholars maintained that fading is an important element of scaffolding (Collins et al., 1989; Dillenbourg, 2002; Puntambekar & Hubscher, 2005; Wood, Bruner, & Ross, 1976), scaffolding customization such as fading/adding has largely been overlooked in the scaffolding design. Nevertheless, among the scaffolding customization methods (i.e., performance-adapted, self-selected, and fixed), performance-adapted scaffolding customization was the most frequent (Belland et al., in press).

Scaffolding strategies. Scaffolding strategies include feedback, question prompts, hints and expert modeling (Belland, 2014; Van de Pol, Volman, & Beishuizen, 2010). Feedback is the provision of information and opinion about students' performance to the students (Belland, 2014). Question prompts help students draw inferences from their evidence and encourage their elaborative learning (Ge & Land, 2003). Hints are clues or suggestions to help students go forward (Melero, Hernández-Leo, & Blat, 2011). Expert modeling presents how experts perform a given task (Pedersen & Liu, 2002). In addition, several types of strategies can be used within one study to satisfy students' different needs according to the contexts (Dennen, 2004; Gallimore & Tharp, 1990).

Discipline. In this paper, "STEM" refers to two things: a) the abbreviation of Science, Technology, Engineering, and Mathematics, in which scaffolding was utilized and b) integrated STEM curricula. Integrated STEM education began with the aim of performance enhancement in science and mathematics education as well as the cultivation of engineers, scientists, and technicians (Kuenzi, 2008; Sanders, 2009). Application of STEM education increased students' motivation and interests in science learning and contributed to positive attitudes towards a STEM-related area (Bybee, 2010). For example, The results of two meta-analyses on the effects of STEM education indicated that the integration of four disciplines showed higher effects ($d > 0.8$) than one or two integrated disciplines of STEM (Becker & Park, 2011; Lam, Doverspike, Zhao, Zhe, & Menzemer, 2008). However, there are few studies investigating the effects of computer-based scaffolding, which has been commonly utilized in each STEM field, in the context of problem-based learning for integrated STEM education. Therefore, it might be worthwhile to investigate the comparison of scaffolding effects between integrated approach in STEM education and each STEM fields. In this regard, integrated STEM education and each STEM discipline are included as discipline moderator. Table 3 shows the moderators and sub-categories of each moderator in this meta-analysis.

Prior Distribution in This Study

In Bayesian analysis, the estimation of the posterior distribution can be mostly affected by how one can set up the prior distribution. Typically, there are three methods to determine the prior distribution. One method is to follow experts' opinion about parameter information related to a certain topic.

Table 3

Moderators in Bayesian Meta-analysis

Moderator	**Higher Order Skills**	**Scaffolding Customization**	**Scaffolding Customization Method (SCM)**
Subcategories	•Analysis •Synthesis •Evaluation	•No fading/adding •Fading •Adding •Fading/adding	•No SCM •Performance-adapted •Fixed time interval •Self-selected
Moderator	**Scaffolding Strategies**	**Scaffolding Types**	**Discipline**
Subcategories	• Feedback • Question prompts • Hints • Expert modeling • Multiple strategies	• Conceptual scaffolding • Metacognitive scaffolding • Strategic scaffolding • Motivational scaffolding	• Science • Technology • Engineering • Mathematics • Integrated STEM

Experts' opinion reflects the results of existing studies, and it is possible that their opinion can represent the current trends about the effects of a certain treatment. Unfortunately, there are few summarized experts' opinion regarding the effects on computer-based scaffolding in PBL. Moreover, even if it exists, that can be a highly subjective point of view. In this regard, this study excluded the use of expert opinion as one of possible prior distribution models. As the second method, one can utilize the results of meta-analysis as a prior distribution. There are two representative meta-analyses related to computer-based scaffolding including intelligent tutoring systems (ITS)- Belland et al. (in press) and Kulik & Fletcher (2015). In the case of Kulik and Fletcher's meta-analysis, their research interests focused on how the effects of computer-based scaffolding including ITS vary in the various contexts of learning environments such as sample size, study duration, and evaluation types. This means that their results did not emphasize the characteristics of ITS. Therefore, it is difficult to utilize this results as prior distribution of this study, which focuses on the characteristics of scaffolding. Recently, a National Science Foundation-funded project (Belland et al., in press) aimed to synthesize quantitative research on computer-based scaffolding. The moderators in this project are overlapped with the many moderators in this study. However, the big difference between the previous TMA and this paper is the learning contexts. This paper only focuses on problem-based learning, but the contexts in the TMA included all kinds of problem-centered instructional models (e.g., inquiry-based learning, Design-based learning, Project-based learning). There exist some differences between several problem-centered instructional models in terms of teachers' roles, learning goals and process, students' learning strategies, and scaffolding usage (Savery, 2006). Therefore, it might be difficult to apply the results of TMA into the informative prior distribution in this paper, which only handled problem-based learning.

The last method to set up the prior distribution is to use non-informative prior distribution. In this paper, several prior distribution models (i.e., uniform, DuMouchel, and Inverse Gamma), which specify the different weighted values of the between-study variance, τ^2, were used to identify the most suitable model-fits for the given data.

Data Coding

Two graduate students who have an extensive knowledge of scaffolding and problem-based learning, as well as coding experience for meta-analysis, participated in coding work. The primary coder selected the candidate studies based on the inclusion criteria and finished the initial codes about the moderators in this study. The second coder also coded the data independently, and then the coding between two coders was compared (See Figure 1). When there was inconsistency of coding between the coders, consensus codes were determined through discussion. The inter-rater reliability by Krippendorff's alpha was calculated when the initial coding was finished. All Krippendorff's Alpha values were above the minimum standard for reliable data - 0.667.

Data Analysis

For data analysis, STATA 14 and WinBUGS 1.4.3 were utilized. WinBUGS 1.4.3 provides Bayesian estimation including prior distributions options by MCMC and

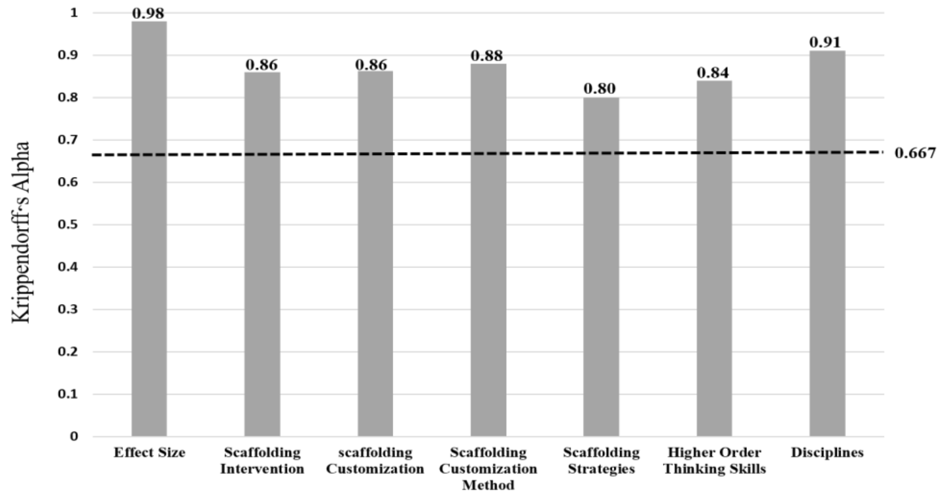


Figure 1. Krippendorff's alpha for inter-rater reliability (dotted line indicates minimum acceptable reliability (Krippendorff, 2004)).

STATA 14 presents the results of model comparisons and the visualization of distributions. Markov chain Monte Carlo simulations were used to sample from a probability distribution of the Bayesian model (Dellaportas, Forster, & Ntzoufras, 2002). Integrating Markov chains can replace unstable or fluctuated initial values of random variables with more accurate values through repetitive linear steps, in which the next state (i.e., the value of variable) can be influenced by the current one, not by preceding one (Neal, 2000). In this process, 22,000 MCMC iterations for estimation of posterior distribution were generated and 2,000 initial iterations were omitted to eliminate initial values that were randomly given. After analysis, Deviance Information Criteria (DIC) was utilized for identifying model fits (Spiegelhalter et al., 2002). A model with the lowest value in DIC is interpreted as the best model to predict the posterior distribution with samples generated by Bayesian inferences of observed data (Spiegelhalter et al., 2004). DuMouchel for ‘scaffolding customization methods’ and uniform prior distributions for all remaining moderators had the smallest value of DIC (See Table 4).

Uniform and DuMouchel assumes different variances between studies (i.e., τ^2), and the results of a certain treatment can be different according to which prior distribution was used, although it has the same dataset. After MCMC generated the posterior distribution of each moderator, the validation of models was investigated through four types of the graphical summary).

Observed Data Characteristics

As shown in Table 5, the number of the observed data points across subcategories within moderators is unbalanced. Especially, in the case of motivation scaffolding, there was no case, and therefore, motivation scaffolding could not be included in this paper. Moreover, around 10.6% of the outcomes included in this paper had small sample sizes (n<10), resulting in the possibility of small-study effects. Therefore, there is a high

Table 4

DIC Values of Prior Distributions

Moderators	Uniform Prior Distribution	DuMouchel Prior Distribution	Inverse Gamma Prior Distribution
Scaffolding	520.25	524.85	523.12
Scaffolding Intervention	93.19	94.27	95.23
Scaffolding Customization	84.58	86.89	87.54
Scaffolding Customization methods	89.30	87.26	90.78
Scaffolding Strategies	133.22	138.45	139.10
Higher Order thinking	117.90	118.23	119.54
Discipline	89.02	91.54	92.21

Table 5

Number of Outcomes according to Subcategories

Higher Order Skills	*N*	Scaffolding Customization	*N*	Scaffolding Customization Methods	*N*
• Analysis • Synthesis • Evaluation	11 14 22	• None • Fading • Adding • Fading/Adding	32 5 3 7	• None • Performance-adapted • Fixed • Self-selected	32 8 4 3
Scaffolding Strategies	***N***	**Scaffolding Type**	***N***	**Discipline**	***N***
• Feedback • Question Prompts • Hints • Expert Modeling • Multiple Strategies	6 24 6 2 9	• Conceptual • Metacognitive • Strategic • Motivational	31 4 12 0	• Science • Technology • Engineering • Mathematics • Integrated STEM	25 7 3 5 7

probability of having biased results in the case of traditional meta-analysis with the above two conditions. In this paper, the possibility of biased results was proved through the normality test of observed data and small-study effects tests.

Normality of observed data. The result of Normality test by Shapiro-Wilk shows the observed data is not normally distributed ($p < 0.05$). The distribution of the effect sizes (Hedge's g) across the studies is moderately right-skewed (skewness > 0) and flat compared to a normal distribution (Kurtosis < 3) as shown in Table 6.

Table 6

Shapiro-Wilk Normality Test

Variable	N	Skewness	Kurtosis	*z*	*p*
Hedge's *g*	47	0.2844	0.1258	0.166	0.04

Small-study effects. Among several methodologies (e.g., funnel plot, Egger's regression test, and trim-and-fill analysis) to discover small-study effects, I first looked over the funnel plot, which shows the visualized plots of effect size and standard error. As shown in Figure 2, some dots as outliers, which represent each study, are located toward the bottom of a funnel plot and out of the central axis of effect sizes. This can be due to a wider range of effect sizes by small sample effects. Therefore, in order to confirm the small sample effects statistically, I conducted Egger's regression to test the null hypothesis of "there are no small-study effects" (see Table 7).

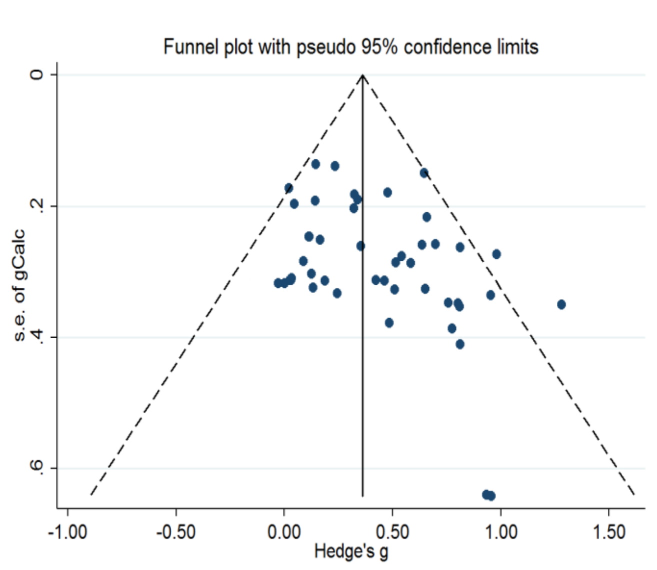


Figure 2. Funnel plots with pseudo 95% confidence limits.

Table 7

Egger's Regression Test for Small-study Effects

	Coefficient	Std. Err.	t	p	95% CI	
					Lower	Upper
Slope	.09	.13	0.72	0.48	-.17	.35
Bias	1.13	.52	2.18	0.04	.08	2.17
Test of H_0 : no small-study effects				0.04		

The result shows that there are small-study effects since the null hypothesis was rejected ($p < 0.05$). Because I could confirm the existence of small-study effects through the funnel plots and Egger's regression test, the trim-and-fill test was unnecessary.

Most meta-analyses have an issue of biased results caused by small-study effects (Kicinski, 2013). The observed data in this study also had small-study effects, which can lead to an overestimation of treatment effects. Therefore, managing the outliers in a meta-analysis can be the essential procedure to reduce the distorted and biased results. Nevertheless, some possible outliers in this study, which located at the bottom of the funnel plot and have the extreme values of effect sizes, were not removed. The reason is that MCMC effectively deals with the outliers through the best weight when it generates samples that can be used for estimating an unknown parameter distribution (Hahn, 2014). This is possible because the range of effect size and standard deviation in the prior distribution was fixed by a certain initial value. Due to the benefit of Bayesian approach for managing outliers, many studies have been conducted to detect outliers within data (Bank, Hietpas, Wong, Bolon, & Jensen, 2014; Ting, D'Souza, & Schaal, 2007; Weiss,

1994) and to demonstrate the effective down-weighting of outliers (Baker & Jackson, 2008).

Interpretation of Bayesian Meta-analysis

Bayesian inference is based on posterior probability, which is in turn based on the likelihood of the observed data, not point or interval estimation from the frequentist approach (i.e., confidence interval-CI) because the standard error gets closer to 0 due to the simulated large number of samples (Robins & Wasserman, 2000). The Bayesian 95% credible interval (CrI) is similar in some ways to the 95% confidence interval (CI) from the frequentist perspective, but there is a big difference between them in terms of basic principle and interpretation (See Table 8). 95% CI means that there is a 95% probability that when calculating the confidence interval by the standard errors of the effect size, the true value of the effect size will fall within the confidence interval. On the other hand, the Bayesian 95% CrI indicates a 95% probability range of value on posterior distribution (i.e., parameters), which is generated by fitting the pre-determined prior distribution including the information of parameters into the observed data. For example, wider CI means huge standard error caused by little knowledge of effects or small samples, but CrI is a range of true effects on treatments at the level of populations. Therefore, most Bayesianists are reluctant to use frequentist hypothesis testing using *p*-values (Babu, 2012; Bayarri & Berger, 2004). However, many scholars interpret the results of Bayesian analysis with the perspective of frequentists, and this causes misunderstanding of results (Gelman, Carlin, Stern, & Rubin, 2014). Table 8 shows the purpose of CI and Crl and the difference in interpretation.

Table 8

Differences between Confidence Interval and Credible Interval

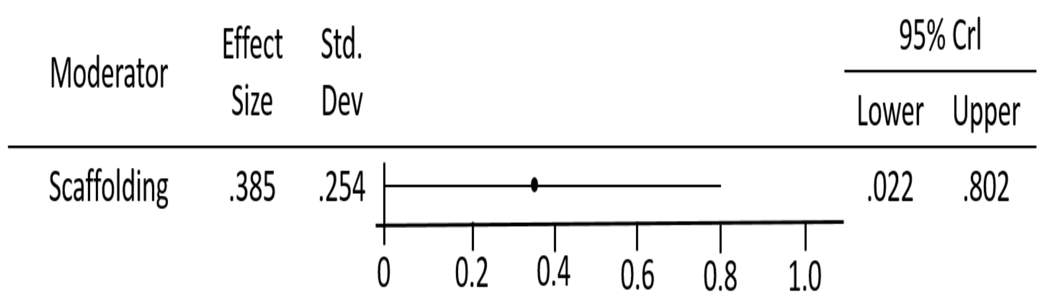
	Confidence Interval	Credible Interval
Purpose	Estimating the sample statistics (data) with the given parameters (ϴ) : *P*(data| ϴ)	Estimating the values of parameters (ϴ) with the given sample statistics (data): *P*(ϴ|data)
Methodology	Frequentist Approach	Bayesian Approach
Major decision factor (Geiger, 1994)	**Standard error** of the mean effect size	The weighted **standard deviation** of the observed data according to the prior distribution
Parameters and data (1)	Parameters: Fixed Data : Random	Parameters: Random Data: Fixed
Steps (Hunter, Schmidt, & Jackson, 1982)	1. Calculating the effect size weighted by sample-sizes 2.The range of confidence interval is generated by the standard error of the mean effect size.	1. Determining μ value from the prior distribution 2.Generating the reasonable range and mean values from the prior distribution as matching the observed data 3.Generating the data from this random mean.
Interpretation (Whitener, 1990)	CI (0.2, 0.7), α=.05, can be interpreted as such There is a 95% probability that **when calculating the confidence interval by the standard errors of the effect size,** the true value of the effect size will fall within the confidence interval (0.2 and 0.7). - The value of CI indicates the **possible** range of effect sizes at the population level based on the estimated means of samples. If one tried to get the parameter value with the given data by frequentist approach, this is wrong.	CrI (0.2, 0.7), α=.05, can be interpreted as such: Given the observed data, the probability is 95% that the true value of the effect size is located in this range of variation - (0.2 and 0.7). - A probability of **parameters** with the fixed credible intervals - The value of CrI directly indicates the variance of effect sizes at the level of population - It is possible to estimate the parameters with the given data in Bayesian approach.

Results

Effect Size of Computer-based Scaffolding

The general effects of computer-based scaffolding compared to the group who did not receive any scaffolding was g = 0.385 (95% CrI = 0.022 to 0.802) based on 20000 simulated iterations. The range of true effect size of computer-based scaffolding are modeled as population statistics from 0.022 to 0.802 with 95% probability, and this means that the groups with computer-based scaffolding showed better learning performance than those without computer-based scaffolding at the level of population, which is normally distributed (θ = 0.385, σ = 0.254, τ^2(0,1000)) (see Figure 3).

In order to verify the model with the above results, graphical summaries were generated (see Figure 4). The result of trace plot in this study showed that the pattern of trace was vertical and dense without any fluctuation of data, and this means that the mean parameter was good-mixed. In addition, in the autocorrelation plots the value of autocorrelation closed to 0 as the lag increased. This indicated that the values generated



Note: MCMC iterations = 22,000, Burn-in = 2,000, MCMC samples = 20,000, 95% CrI: 95% Credible Interval

Figure 3. Effect size of scaffolding.

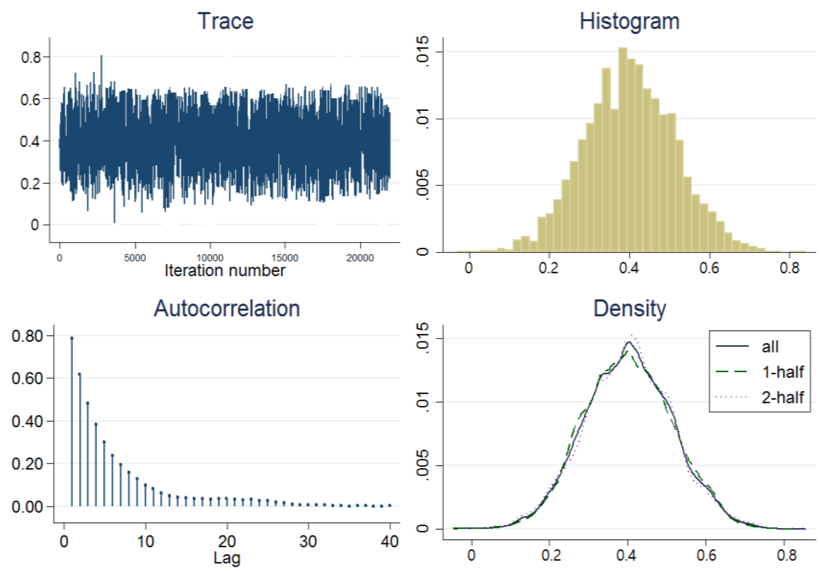


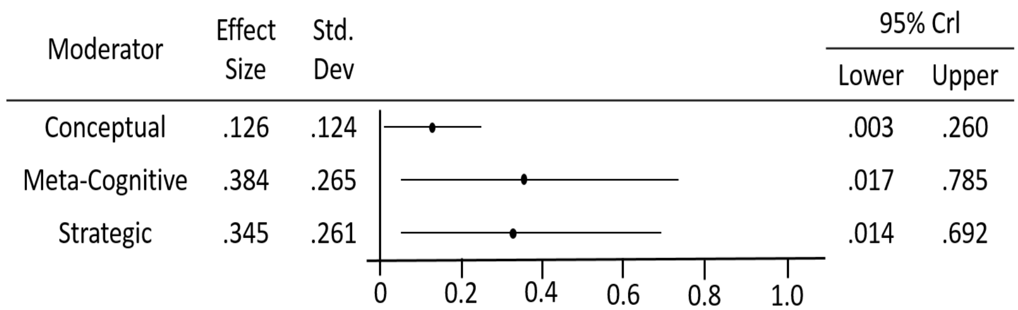
Figure 4. Graphic summaries for overall effects of computer-based scaffolding.

by each lag were independent. Furthermore, histogram and density plots provided evidence supporting a normal distribution of the generated samples.

Subgroup Analysis

The non-informative prior distribution, which was utilized in this study, considers all possible τ^2 (between-study heterogeneity) across the studies, and it justified sub-group analysis to identify the potential moderator variables. This study has six moderators (i.e., scaffolding intervention, scaffolding customization, scaffolding customization methods, scaffolding strategies, higher order thinking, and discipline).

Scaffolding intervention. Students who received computer-based scaffolding showed better cognitive outcomes in STEM education than those who did not receive any scaffolding (see Figure 5). The effect size was largest for meta-cognitive scaffolding (g = 0.384, 95% CrI = 0.17 to 0.785), followed by Strategic (g = 0.345, 95% CrI = 0.14 to



Note: MCMC iterations = 22,000, Burn-in = 2,000, MCMC samples = 20,000, 95% CrI: 95% Credible Interval

Figure 5. Effect size of sub-categories within scaffolding intervention.

0.692) and Conceptual scaffolding (*g* = 0.126, 95% CrI = .003 to .260).

The generated samples by MCMC were well mixed as shown in Figure 6. In the trace plots, all data were stable and did not show any sharp changes. Moreover, the results of autocorrelation were close to 0 and the histogram and density plots indicated the normal distribution of the simulated data.

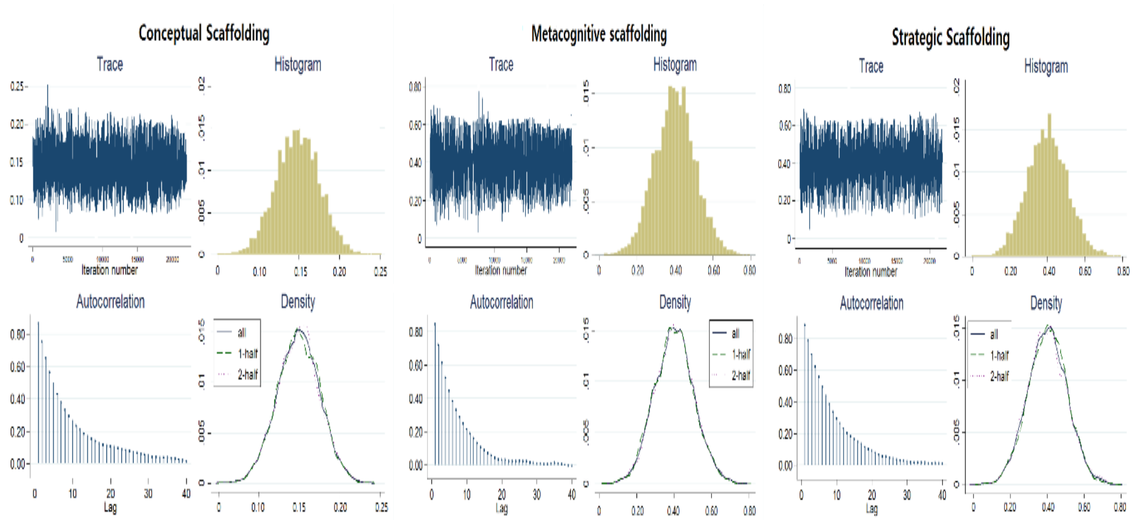
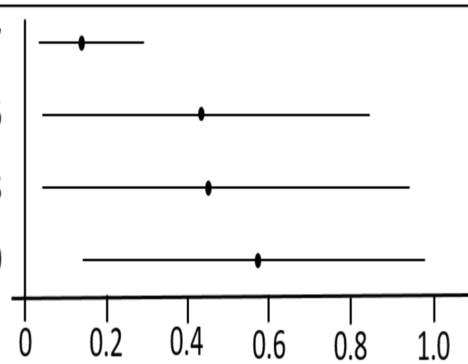


Figure 6. Graphic summaries for effects of scaffolding intervention.

Scaffolding Customization. When students received customized scaffolding, the effects of scaffolding were noticeably higher than no customized scaffolding and no scaffolding (see Figure 7). Among scaffolding customization types, fading/adding showed the highest effect sizes (g = 0.590, 95% CrI = 0.155 to 0.985) compared to fading (g = 0.429, 95% CrI = 0.015 to 0.865) and adding scaffolding (g = 0.443, 95% CrI = 0.012 to 0.957). Each scaffolding customization type showed a wide range of true effect sizes at the level of population based on the Credible Intervals, but it is clear that applying scaffolding customization shows better effects on students' learning performance than no scaffolding customization at the level of population.

There were no issues in terms of convergence, standard errors, and normality of the generated samples by MCMC, and the results of scaffolding customization represented the parameters as shown in Figure 8.

Moderator	Effect Size	Std. Dev	95% CrI Lower	95% CrI Upper
None	.162	.147	.006	.345
Fading	.429	.286	.015	.865
Adding	.443	.288	.012	.957
Fading/Adding	.590	.270	.155	.985



Note: MCMC iterations = 22,000, Burn-in = 2,000, MCMC samples = 20,000, 95% CrI: 95% Credible Interval

Figure 7. Effect size of sub-categories within scaffolding customization.

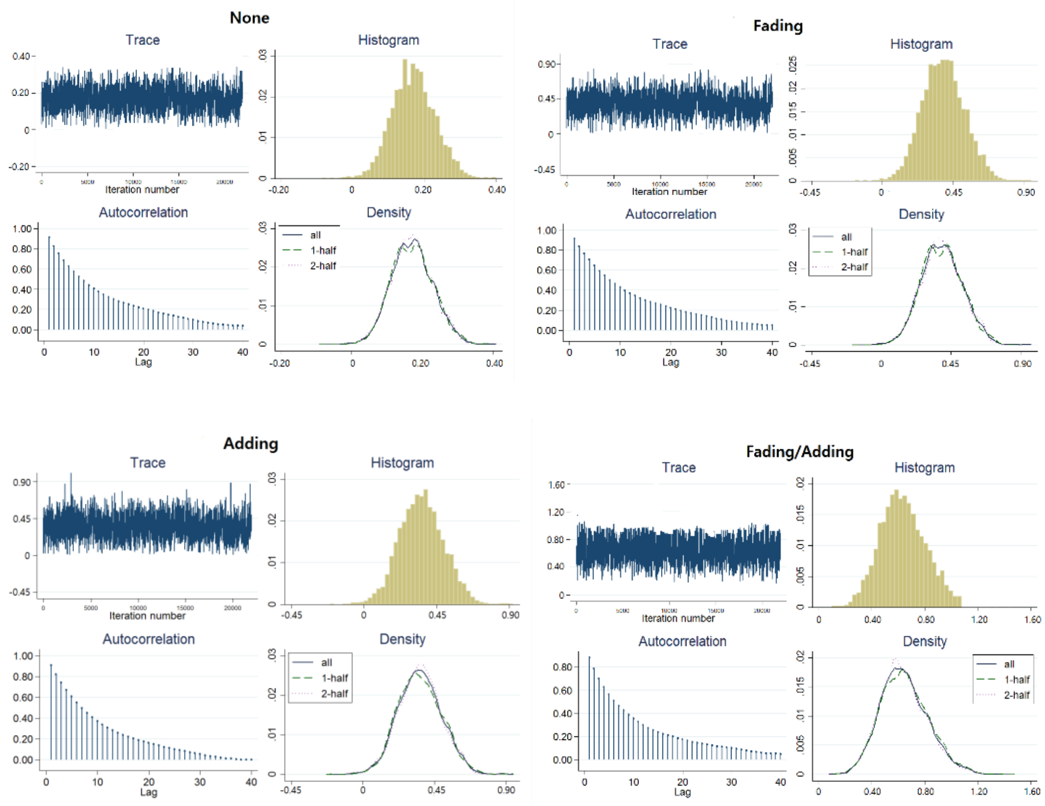
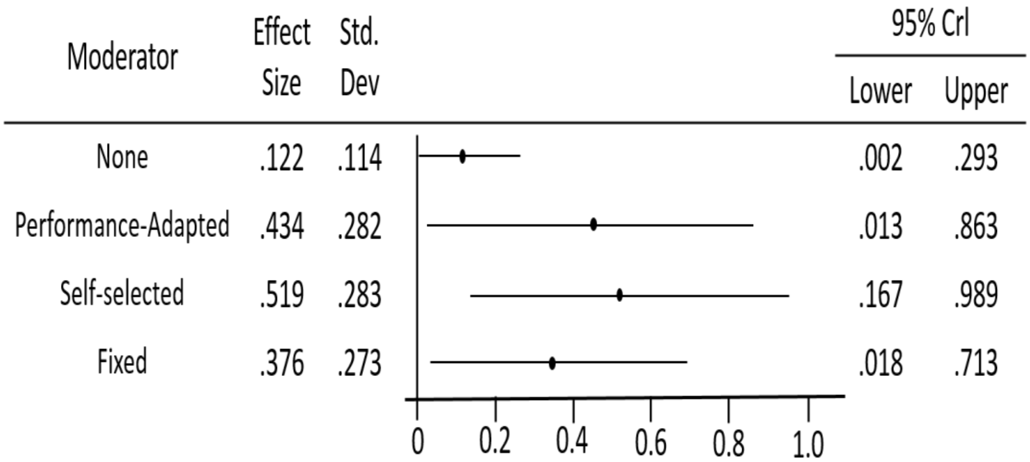


Figure 8. Graphic summaries for effects of scaffolding customization.

Scaffolding customization methods. Scaffolding customization proceeds according to performance-adaption, self-selection, and fixed time intervals. When scaffolding was customized based on self-selection, the effect sizes of scaffolding was higher (g = 0.519, 95% CrI = 0.167 to 0.989) than other scaffolding customization methods: Fixed time interval (g = 0.376, 95% CrI = 0.018 to 0.713) and performance-adaption (g = 0.434, 95% CrI = 0.013 to 0.863) as shown in Figure 9.

None means both no scaffolding customization and no scaffolding customization methods. Nevertheless, the effect sizes between two “Nones” from scaffolding customization (g = 0.162) and scaffolding customization methods (g = 0.122) were



Note: MCMC iterations = 22,000, Burn-in = 2,000, MCMC samples = 20,000, 95% CrI: 95% Credible Interval

Figure 9. Effect size of sub-categories within scaffolding customization methods.

slightly different although the data for two moderators was exactly the same. One possible reason is the usage of different prior distributions, which assume different variance between the studies (τ^2). The uniform prior distribution utilized in the scaffolding customization model weighted the larger value of τ^2 than the Dumouchel prior distribution in the scaffolding customization methods model. Therefore, none in the category scaffolding customization had wider CrIs than one in the scaffolding customization methods category. The results of graphical summaries demonstrated the well-mixed MCMC chains about the generation of samples (see Figure 10).

Scaffolding strategies. Scaffolding can assume several forms such as hints, feedback, question prompts, expert modeling, and multi-forms as a combination. The results show that the effect size for expert modeling (g = 0.523, 95% CrI = 0.030 to 0.979) and feedback (g = 0.474, 95% CrI = 0.026 to 0.968) approached a middle level.

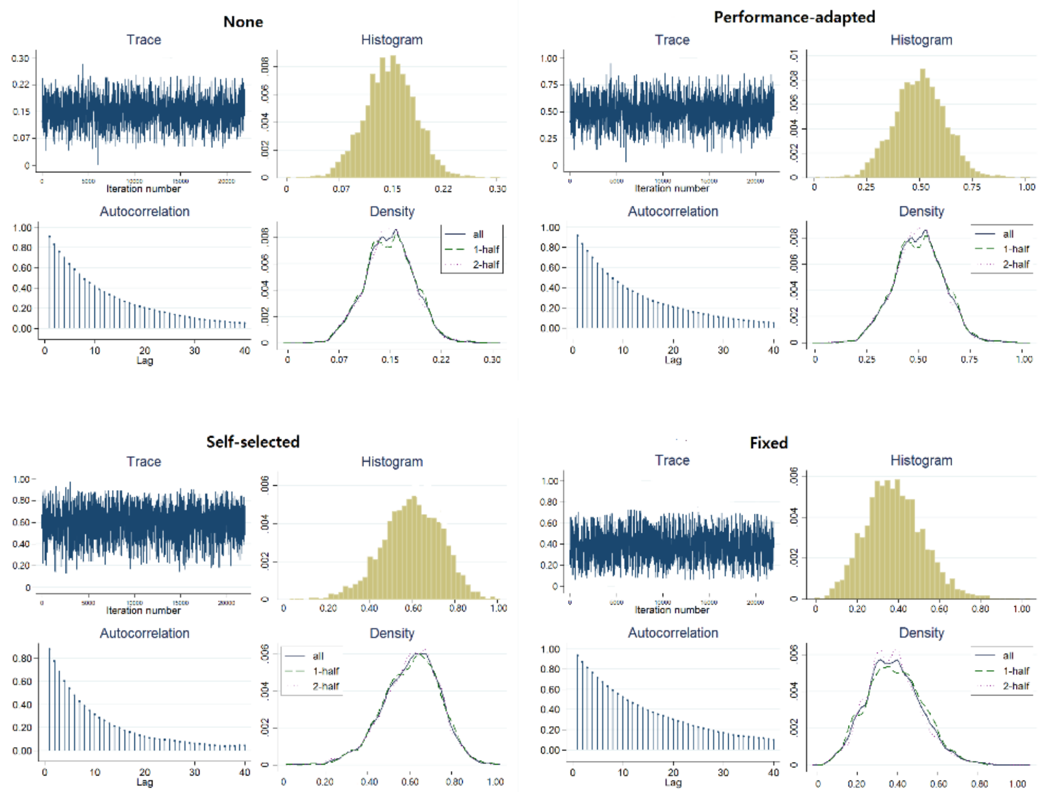
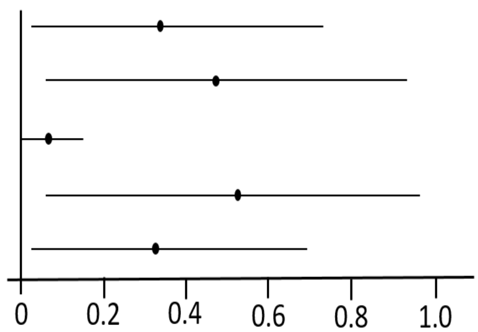


Figure 10. Graphic summaries for effects of scaffolding customization methods.

Other forms (i.e., hints (g = 0.375, 95% CrI = 0.013 to 0.742) and multi-forms (g = 0.340, 95% CrI = 0.012 to 0.698) also had relatively higher effects on students' cognitive outcomes than students who did not receive the scaffolding (see Figure 11). However, in the case of question prompts, there was no evident difference (g = 0.078, 95% CrI = 0.003 to 0.156) as compared to the control group in terms of the effect size. The stability of MCMC chain and the normality of generated samples had no problems, but in the case of autocorrelation, the correlation did not rapidly drop toward 0 as the lag increases (see Figure 12). This can cause inaccurate prediction of parameters due to the correlation of the values generated from each lag. This issue could be caused by

Moderator	Effect Size	Std. Dev	95% CrI Lower	95% CrI Upper
Hints	.375	.271	.013	.742
Feedback	.474	.283	.026	.968
Question Prompts	.078	.059	.003	.156
Expert Modeling	.523	.280	.030	.979
Multi-Forms	.340	.257	.012	.698



Note: MCMC iterations = 22,000, Burn-in = 2,000, MCMC samples = 20,000, 95% CrI: 95% Credible Interval

Figure 11. Effect size of sub-categories within scaffolding strategies.

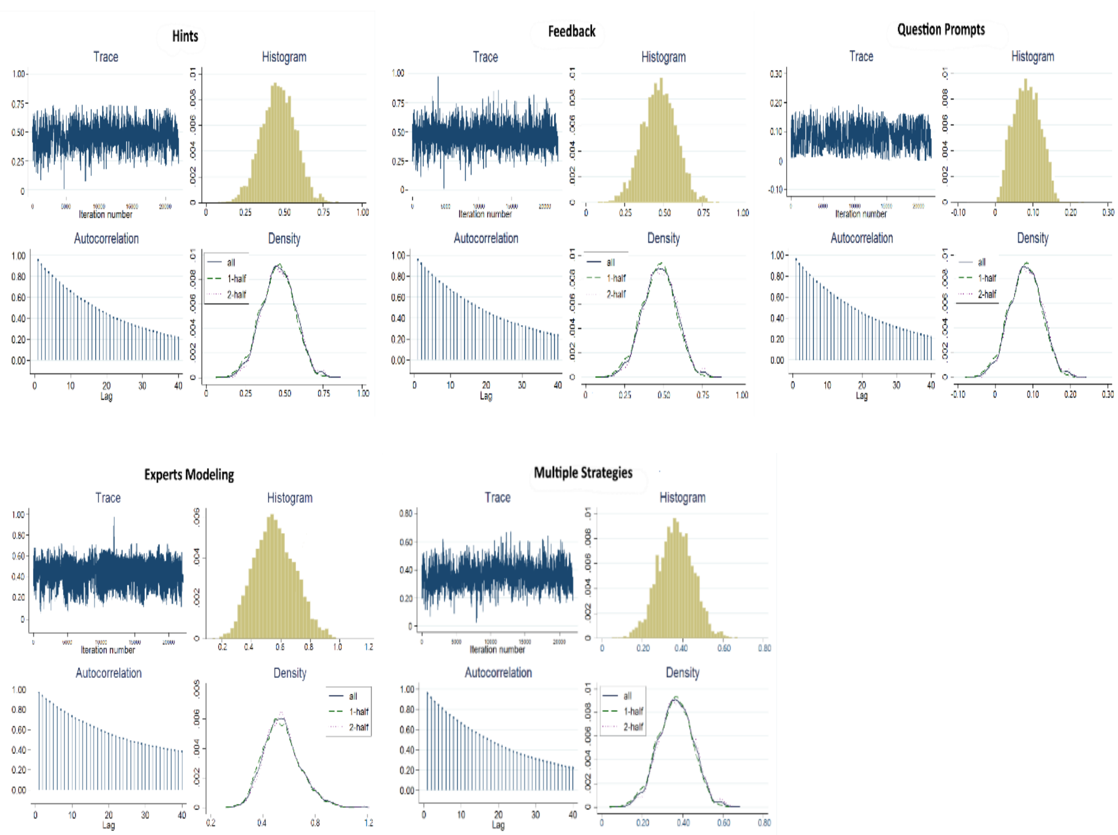
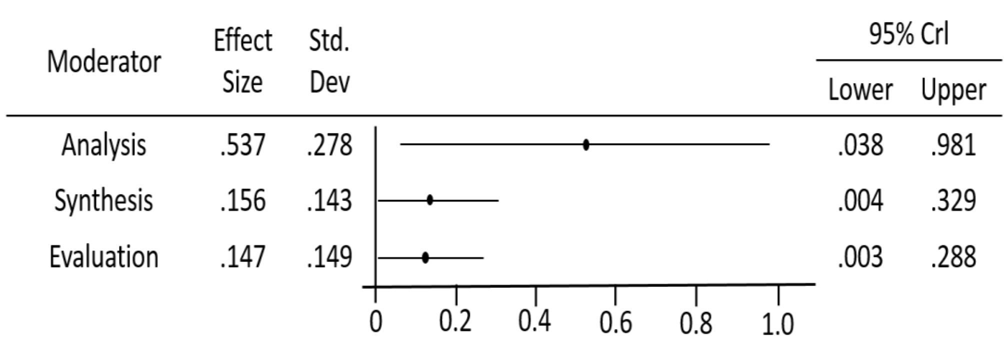


Figure 12. Graphic summaries for effects of scaffolding strategies.

inadequacy of the observed samples for the predetermined prior distribution or by the wrong selection of prior distribution. However, it was clear that the autocorrelation of these categories was evidently reduced and closer to 0 as the lags increased. This means that the values simulated by MCMC accurately predict each parameter of the categories (Geyer, 2010). Therefore, the convergence by MCMC did not have any problems to simulate the data for scaffolding strategy.

Higher order thinking. Higher order thinking is one of the important intended outcomes expected by scaffolding. When scaffolding intended to improve students' analysis ability, which identifies the components of information and ideas and establish the relations between elements, the effect size was highest at the population level (g = 0.537, 95% CrI = 0.038 to 0.981). However, higher order thinking skills related to synthesis (g = 0.156, 95% CrI = 0.004 to 0.329) and evaluation (g = 0.147, 95% CrI = 0.003 to 0.288), which require higher level application of knowledge than analysis ability, were not improved to a large extent by computer-based scaffolding (see Figure 13).



Note: MCMC iterations = 22,000, Burn-in = 2,000, MCMC samples = 20,000, 95% Crl: 95% Credible Interval

Figure 13. Effect size of sub-categories within higher order skills.

The graphical summaries demonstrated no issues that the outcomes from the samples generated by MCMC represent the parameters of higher order skills due to well-mixed data (see Figure 14).

Discipline. Scaffolding had higher effect sizes when it was used in Engineering (g = 0.528, 95% CrI = 0.025 to 0.983), Technology (g = 0.379, 95% CrI = 0.011 to 0.782), and Mathematics education (g = 0.425, 95% CrI = 0.024 to 0.883) than when it was utilized in Science (g = 0.146, 95% CrI = 0.003 to 0.295) as shown in Figure 15. In the case of integrated STEM education, which integrated the content and process of disciplines, the effect size was relatively lower (g = 0.201, 95% CrI = 0.005 to 0.428).

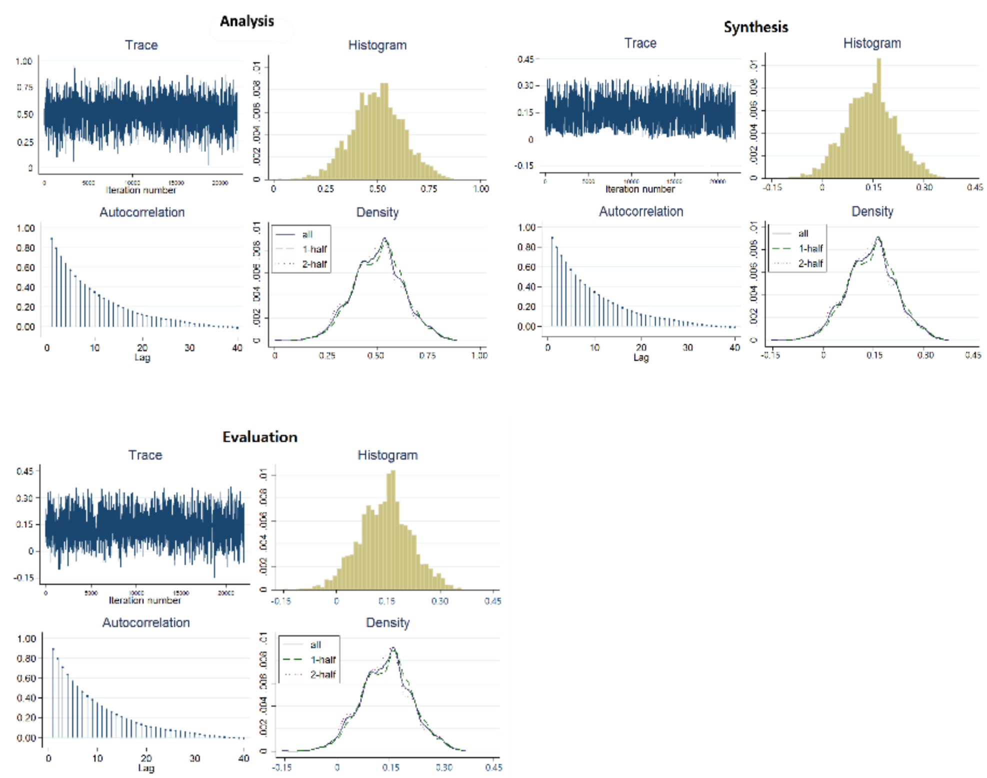
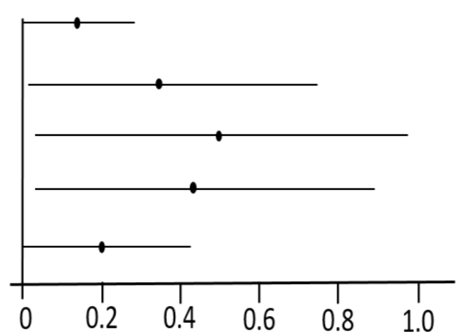


Figure 14. Graphic summaries for effects of computer-based scaffolding on higher-order Skills.

Moderator	Effect Size	Std. Dev	95% Crl Lower	95% Crl Upper
Science	.146	.133	.003	.295
Technology	.379	.227	.011	.782
Engineering	.528	.301	.025	.983
Mathematics	.425	.249	.024	.883
Integrated STEM	.201	.179	.005	.428



Note: MCMC iterations = 22,000, Burn-in = 2,000, MCMC samples = 20,000, 95% Crl: 95% Credible Interval

Figure 15. Effect size of sub-categories within discipline.

Figure 16 showed that the generated samples were well-mixed by MCMC, and the results of BMA can represent the parameters.

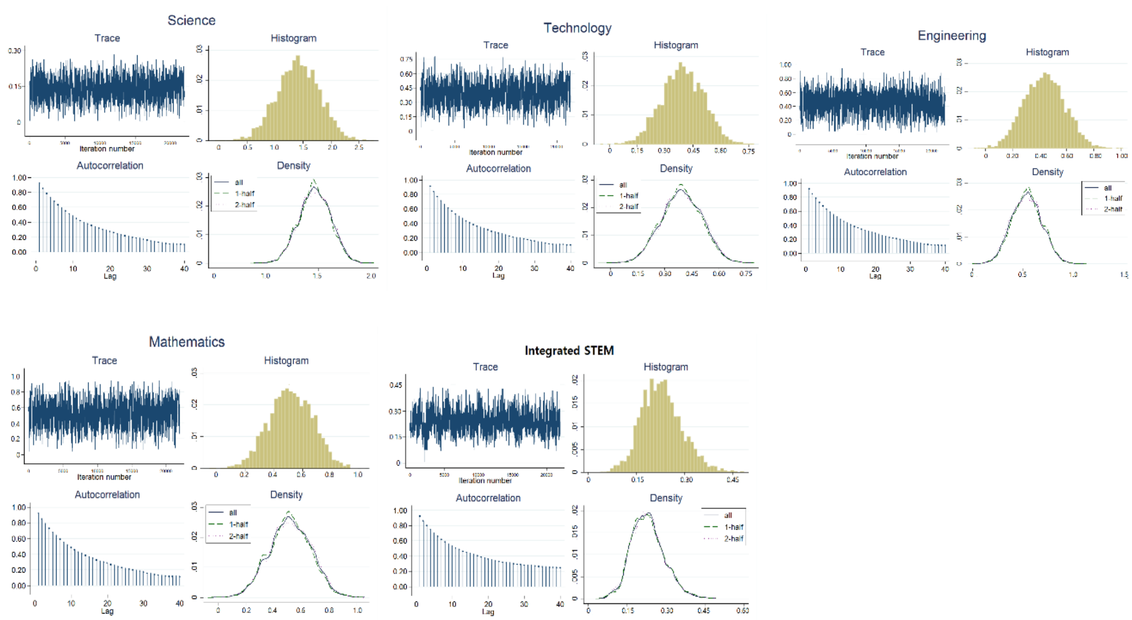


Figure 16. Graphic summaries for effects of computer-based scaffolding on disciplines.

Discussion

Overall Effects of Computer-based Scaffolding

The overall effect size of computer-based scaffolding obtained from Bayesian Meta-analysis was g = 0.385, which would be labeled as between small and moderate effect size by Cohen (1988). This result means that computer-based scaffolding utilized in the context of problem-based learning for STEM education is an effective means to improve students' higher order skills and learning outcomes. The estimations of effect sizes in this meta-analysis parallel the results from other meta-analyses on the effects of computer-presented feedback (g = 0.35; Azevedo & Bernard, 1995) and on the effectiveness of computer-based supports (g = 0.37) (Hattie, 2008) despite different contexts of scaffolding usages.

Effects of the characteristics of scaffolding

The computer-based scaffolding interventions included in this paper all came from the context of problem-based learning (PBL). PBL requires students to hypothesize the solution of ill-structured problems, to verify their claims with reasonable evidence, and to reflect on their learning performance. In large part, whether the student can successfully navigate each of these PBL requirements, depends on the students' higher order thinking skills. From this sense, the student's ability to reflect on their own thinking (metacognition), is regarded as essential to successful PBL learning. Moreover, students' own learning strategies are also important to help make the complicated PBL procedure more accessible and understandable as enhancing self-directed learning and lifelong learning skills (Hmelo-Silver, 2004; Schoenfeld, 1985). Several studies have demonstrated the importance of metacognition and learning strategies to improve students' learning outcomes in Problem-based learning (Downing, Kwong, Chan, Lam, & Downing, 2009; Sungur & Tekkaya, 2006). The results of BMA corresponding with the above studies showed meta-cognitive (g = 0.384) and strategic scaffolding (g = 0.345) led to relatively large effects on students' learning outcomes in the context of Problem-based learning. On the other hand, conceptual scaffolding did not show large overall effects (g = 0.126) on learning as compared to the control groups. The low effects of conceptual scaffolding may be explained by the fact that the tasks in problem-based learning do not just require students' identification of several things considered when investigating the problem, but also request students' ability to apply the knowledge into the real word (Barrows, 1996).

Adjustment of supports has been recognized as an effective component of scaffolding from the original definition of scaffolding (Wood, Bruner, & Ross, 1976) and some scholars emphasized the role of fading (Collins et al., 1989; Dillenbourg, 2002; Puntambekar & Hubscher, 2005) and adding (Koedinger & Aleven, 2007; Koedinger & Corbett, 2006) as adjustment mechanisms of scaffolding. According to Adaptive Control of Thought – Rational theory, human knowledge is gained through the integrated productions from the declarative and procedural memory modules (Anderson, Matessa, & Lebiere, 1997). That is, successful performance in learning depends on each student's amount of the existing knowledge and the ability to retrieve and apply the relevant knowledge from their memory for the given tasks. Therefore, scaffolding should be adjusted in order to satisfy each student' different needs and ability (Wood et al., 1976).

Especially in PBL, which requires students' advanced self-directed learning in the ill-structured and complex tasks, each student can experience diverse challenges such as a lack of prior knowledge, problem-solving skills, and reflective thinking skills (Jones, 2006). In this sense, scaffolding in PBL should be faded to reduce the insufficient supports and added when the provided scaffolds do not positively affect students' learning. Nevertheless, the importance of scaffolding customization in PBL has been overlooked and few studies in PBL utilized fading and adding function in their scaffolding design. Among the included outcomes in this meta-analysis, much scaffolding did not incorporate fading (10%) and adding (6%). This means that it might have been difficult to generalize the effects of fading and adding by meta-analysis. However, according to BMA, which overcomes this issue, when fading and adding were combined, scaffolding's effects were highest (g = 0.590) in comparison to other scaffolding customization levels. Moreover, scaffolding that incorporates adding (g = 0.443) showed better effects than that which only incorporates fading (g = 0.429). However, all kinds of scaffolding customization (i.e., fading, adding, and fading/adding) have larger effect sizes than no scaffolding customization (g = 0.162) in the context of PBL. This result indicates the important role of fading and adding of scaffolding in student success in problem-based learning, contrary to Belland et al. (in press)'s meta-analysis reporting no differences in terms of effectiveness between fading/adding and no customized supports in the context of all problem-centered instructional models. This is because fading and adding of scaffolding in PBL can be an essential component to support students' accomplishment of the given tasks as several scholars theoretically emphasized the importance of fading (Collins et al, 1989) and adding (Koedinger & Aleven, 2007) on improving students' self-directed learning. This skill can play an important role in PBL that requires students' multiple solutions and higher order thinking for solving complicated, ill-structured tasks.

In addition, according to how one customizes scaffolding (i.e., self-selected, performance-adapted, and fixed-time intervals), the effects of scaffolding varied. When scaffolding was customized by students' self-selection, its effect was highest (g = 0.519). In addition, if scaffolding can be changed by the assessment of student performance, its effects of scaffolding was relatively high (g = 0.434). Two methods of scaffolding customization by students' self-selection and the assessment of performance have mostly been utilized by intelligent tutoring systems (Belland, 2016). Nevertheless, the result showed higher effects of scaffolding customization by self-selection than by performance-adoption. This indicates that computer-systems might be still not advanced enough to effectively and efficiently determine the scaffolding customization through continuous and dynamic diagnosis of students' learning progress rather than students' own decision (Graesser, Chipman, Haynes, & Olney, 2005; Graesser, VanLehn, Rosé, Jordan, & Harter, 2001). In addition, even when scaffolding change happened by a fixed schedule without consideration of students' learning status and self-decision, the effect of scaffolding (g = 0.376) was better than one of no scaffolding customization (g = 0.122). Based on the results of scaffolding customization and its method, adding as well as fading should be considered to improve students' learning performance in PBL, and regarding its method, self-selected scaffolding customization may be most effective.

Various scaffolding strategies played a role in improving learning performance in Problem-based Learning for STEM education. This corresponds with the positive results of hints (Raphael, Pressley, & Mohan, 2008), expert modeling (Pedersen & Liu, 2002), and feedback (Rouinfar et al., 2014) from previous empirical studies. However, the results indicated that providing multiple strategies of scaffolding in one scaffolding system is counter-productive rather than one strategy in one scaffolding system. This can be supported by several scholars’ claims that multiple forms of scaffolding regardless of students’ current needs and learning status can be less effective (Aleven & Koedinger, 2002; Azevedo & Hadwin, 2005; Baylor & Kim, 2005). One interesting result in terms of scaffolding strategies is that question prompts had the smallest effect size ($g = 0.078$) among the scaffolding strategies (e.g., expert modeling, hints, and feedback). One of the main advantages posited for question prompts is to improve students’ metacognition (Chen & Bradshaw, 2007; Davis, 2003; Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989) by helping students draw inferences from their evidence and encourage their elaborative learning. One possible reason why the effect of question prompts to enhance metacognition is smallest is that other strategies of scaffolding might be preferred as the form of metacognitive scaffolding to question prompts to induce more advanced students’ reflective thinking and critical thinking (Quintana, Zhang, & Krajcik, 2005). This result supports Lee and Chen's (2009) claim that question prompts might be not an effective support to improve students’ higher order thinking skills including metacognition, especially in ill-structured instruction.

When scaffolding was intended to help students identify the components of information and ideas (i.e., analysis level of higher order thinking), its effect size was much higher than when supporting the recognition of the patterns of components (synthesis level) and judging the value of data for justifying conclusion (evaluation level). This can be a limitation of computer-based scaffolding because it might be really difficult for computer-systems to identify students' challenge and expanded use of the mind about the information required from PBL. Therefore, scaffolding can be effectively provided at the level of analysis.

The effect of scaffolding was highest (g = 0.528) when it was used in the context of Engineering. Mathematics and Technology education have been regarded as pre-requisite subjects for engineering courses in K-12 education (Douglas, Iverson, & Kalyandurg, 2004). Therefore, the high effects of scaffolding across Engineering, Mathematics, and Technology (EMT) are understandable due to the curriculum sharing and similarity of problem-solving process. However, in the case of problem-based learning for science education, BMA showed a relatively lower effect size (g = .146) than other disciplines (i.e., Technology, Engineering, and Mathematics). In science education, many scholars have engaged in debates on the proper instructional design, the characteristics of scaffolding, and curriculum, and this led to an inconsistency in scaffolding design among science education researchers (Lin et al., 2012). This inconsistency can cause ineffective scaffolding in science education. Another possible reason is that science education in PBL requires students' advanced scientific inquiry and higher order thinking skills (Tang et al., 2016). But Zohar and Barzilai (2013) claimed that students' identification of what should be considered for problem-solving by understanding of content knowledge in science education should take precedence over enhancing higher-order thinking skills. However, conceptual scaffolding in this study showed a lower effect size (g = 0.126) than those of other types of scaffolding. Therefore, it might be difficult for students to get effective supports from conceptual scaffolding for identification of problematic situation and a better understanding of content knowledge, and it resulted in low effects of scaffolding in science learning. In addition, scaffolding on integrated STEM education also showed a low effect size (g = 0.201).

Ill-structured problems in PBL cannot be solved by mere application of existing knowledge because problem-solving on this type of problems requires student's advanced thinking process and strategy rather than the recall of information (Beyer, 1997). In this sense, Hmelo-Silver and Ferrari (1997) argued that higher order thinking skills including analysis, synthesis, and evaluation of knowledge can be one of the essential abilities to accomplish the tasks in PBL. Higher order thinking skills allow students to a) understand the given problematic situation and to identify the gaps in their knowledge to solve the problem, and b) apply knowledge to find the solution to the problem (Hmelo-Silver & Lin, 2000). Students can enhance higher-order thinking skills through active participation in such activities as making hypotheses, gathering evidence, and generating arguments (Lewis & Smith, 1993). Many studies indicated that computer-based scaffolding can enhance students' higher-order thinking skills (Chang et al., 2001; Rosen & Tager, 2014; Zydney, 2005, 2008). Nevertheless, the results of BMA demonstrated that computer-based scaffolding was not sufficient supports for every level of higher-order thinking skills (i.e., analysis, synthesis, and evaluation of knowledge). When scaffolding was intended to help students identify the components of information and ideas (i.e., analysis level of higher order thinking), its effect size (g = 0.537) was much higher than when supporting the recognition of the patterns of components (synthesis level) (g = 0.156) and judging the value of data for justifying conclusion (evaluation level) (g = 0.147). In other words, computer-based scaffolding was very helpful for students to understand the problematic situation and to compare information required to find out the solutions (i.e., analysis level). However, computer-based scaffolding often struggles to effectively support students as they a) build new knowledge by reorganizing existing information (i.e., synthesis level) and b) validate their claims based on this new knowledge (i.e., evaluation level). This corresponds with many researchers' claims that students still encountered the difficulty in improving higher-level (i.e., synthesis and evaluation) of higher-order thinking skills in spite of computer-based supports (Jonassen, 1999b). This result has an important implication that scaffolding design for improving students' higher order thinking should be differentiated according to which level of higher order thinking is addressed in PBL.

Limitations and Suggestions for Future Research

Reliability of Results

The results of BMA are estimated based on probabilistic inferences. However, the probability cannot necessarily say what is actually done in the real world, and it is just a prediction. The results of BMA were reasonable with a high level of probability, but an exception can occur. Thus, one should not have blind faith in the BMA results. In order to minimize this limitation, many researchers are trying to develop new techniques of Bayesian analysis, but the frequentist method might theoretically bring more accurate results of Meta-analysis if the observed data with large samples satisfies the all statistical conditions, which do not cause any bias of results. However, there have been few studies to directly compare the results from BMA and TMA, and it might be difficult to tell about which approach among BMA and TMA can bring more reliable results. Therefore, a follow-up study is required to verify the effects of BMA as an alternative to TMA.

The Selection of Prior Distribution

The estimation of posterior distribution is largely influenced by how one set up the prior distribution (Findley, 2011; Lewis & Nair, 2015). For example, if one generates the prior distribution with a certain value of mean and variance, the distribution of each observed data can be matched with this predetermined prior distribution. This means that posterior distribution simulated by the prior distribution and likelihood also has the same pattern of parameters with prior distribution. Therefore, the results of BMA can be different according to how researchers set up the prior distribution. To solve this issue, in the medical field, in which BMA has been commonly used, the use of informative prior distributions rather than non-informative prior distributions has been gradually increased due to the accumulated data of treatments obtained from several meta-analyses with same or similar topics and moderators (Turner, Jackson, Wei, Tompson, & Higgins, 2015). This accumulated data can serve as the standard value of prior distribution for future BMA, resulting in the possibility of informative prior distribution. This informative prior distribution predicts the posterior distribution more accurately and effectively than the non-informative prior distribution, which just assumes the normal distribution of parameter with the prior information of a certain treatment. However, in educational field, there are few meta-analyses utilizing informative prior distribution due to a lack of consensus among scholars and prior meta-analysis on certain research topics or educational tools. Hopefully, the results of this study will play a role as the informative prior distribution for the effectiveness of computer-based scaffolding in PBL, which allows the following meta-analysis on this topic to build up the identical prior distribution model.

Expansion of Research Scope

This study only handled computer-based scaffolding and students' cognitive outcomes as the results in the context of Problem-based Learning for STEM education. However, scaffolding including one to one scaffolding and peer scaffolding, as well as computer-based scaffolding, have been commonly utilized in various educational environments and purposes (e.g., English language skills, and students with disabilities). Therefore, Bayesian meta-analysis with a broad subject of scaffolding as future research is also needed.

Conclusion

This Bayesian meta-analysis demonstrated the effectiveness of computer-based scaffolding on students' learning performance and higher order thinking skills in the context of Problem-based learning for STEM education. Currently, many researchers have been interested in designing and developing computer-based scaffolding. However, various types of scaffolding are often utilized without considering the characteristics of the given learning contexts. For example, the goal of problem-based learning is not to improve students' content knowledge, but to enhance students' advanced problem-solving skills and thinking strategies based on the application of the existing knowledge (Savery, 2015). Nevertheless, conceptual scaffolds have been mostly used in the context of PBL based on the results of BMA, but its effectiveness on PBL is imperceptible. This indicated that instructional designers should focus more on the metacognitive and strategic scaffolding interventions to improve students' problem-solving skills using their own learning strategies in the learning context of PBL.

The most interesting result in this paper is on the effects of adding scaffolding customization. Adding scaffolding has often been disregarded in the context of PBL. But in PBL, which requires students' different abilities such as information-searching strategy, problem-solving skills, creative thinking, and collaborative learning skills, adding scaffolding should be considered as an effective strategy for promoting strong learning outcomes. In addition, when scaffolding customization occurs by students themselves, its effects may be best because self-selected scaffolding can improve students' self-directed learning and motivation toward their learning. According to the results, question prompts have been mostly utilized as one strategy of computer-based scaffolding, but its effect was not huge as much as many scholars believed (Choi, Land, & Turgeon, 2008; Ge & Land, 2003). The original goal of scaffolding to address this issue might be considered. The main purpose of scaffolding is to help students improve engagement in learning and successfully accomplish the given tasks that are beyond their current abilities (Wood et al, 1976). However, if the question prompts in PBL are provided in a complicated and difficult manner, the question prompts can be a hindrance of learning instead of support. Therefore, this paper suggests that more simple and directive supports such as hints and expert modeling are more suitable for PBL.

CHAPTER IV

ENHANCING HIGH SCHOOL STUDENTS' INFORMATION LITERACY AND ARGUMENTATION SKILLS THROUGH COMPUTER-BASED SCAFFOLDING IN PROBLEM-BASED LEARNING FOR SCIENCE LEARNING

Abstract

The goal of problem-based learning (PBL) is to help students construct knowledge through engagement in the scientific inquiry process and evaluation of claims. For successful PBL, students need advanced information literacy and argumentation skills to effectively gather, evaluate, and utilize information and data, and then to clarify and justify claims using evidence. The purpose of this study is to design and implement computer-based scaffolds systems (i.e., *Virtual Field Trip* and *Connection Log*) to improve high school students' information literacy and argumentation skills in PBL with a scientific task. The results obtained by mixed research methods demonstrated the effects of computer-based scaffolding on improving students' two skills in PBL. Furthermore, this study identified students' various experiences in the problem-solving process as a function of their different levels of information literacy and argumentation skills. The results imply that information literacy and argumentation skills supported by computer-based scaffolding are pivotal factors in PBL for science learning, which should not be overlooked.

Keywords: Problem-based Learning, Science Education, Information Literacy, Argumentation skills, Computer-based Scaffolding, Virtual Field Trips.

Introduction

The goal of problem-based learning (PBL) is to help students construct knowledge through engagement in the scientific inquiry process and evaluation of claims (Hmelo-Silver & Barrows, 2015). In this sense, many scholars emphasized the importance of information literacy to evaluate and validate information to support their ideas about the solutions (American Library Association, 2000) and argumentation skills to clarify and justify claims using evidence in PBL (Belland, 2010). However, K-12 students sometimes have difficulty engaging in PBL due to inadequate information literacy and argumentation skills. To address this issue, many computer-based scaffolds have been designed and implemented to enhance K-12 students' information literacy (Wiley, Goldman, Graesser, Sanchez, Ash, & Hemmerich, 2009) and argumentation skills (Harney, Hogan, Broome, Hall, & Ryan, 2015; Hsu, Chiu, Lin, & Wang, 2015). However, the learning context where these scaffolds were utilized was not PBL, and it is not clear that these scaffolds would be effective in the context of PBL, which has different defining characteristics (e.g., ill-structured problems and its constructivist framework). This makes it difficult to identify what needs to be emphasized to help students proceed with learning in PBL.

The purpose of this study is to address these gaps by developing and testing two types of scaffolding software that help high school students (10th and 11th grade) improve information literacy and argumentation skills through individualized help while they do science learning in PBL. In addition, this study investigated how information literacy and argumentation skills supported by computer-based scaffolding affect high school students' problem-solving process in PBL. In the following sections, I review related literature and introduce my research design. Then, I report the results of a mixed-method analysis and discuss the results.

Literature Review

Problem-Based Learning

Problem-based learning (PBL) is a pedagogy designed to enhance students' problem-solving skills by inviting students to address authentic, ill-structured problems (Scheiman & others, 1989). PBL can also promote life-long learning skills (Barrows, 1996) by helping students learn to adjust to a fast-changing society through scientific argumentation (Uyeda, Madden, Brigham, Luft, & Washburne, 2002). PBL has positively affected students' motivation (Savery, 1999), knowledge acquisition (Strobel & Van Barneveld, 2009), and higher order thinking skills (Gijbels, Dochy, Bossche, & Segers, 2005) in various disciplines. PBL typically follows seven steps - a) Defining the problem, b) Gathering information, c) Sharing information, d) Generating possible solutions, e) Determining the best-fit solution, f) Presenting the solution, and g) Debriefing the problem (Hmelo-Silver, 2004; Sage & Torp, 2002). These steps require students' self-directed learning and scientific inquiry and thus differ from the procedure of teacher-centered instruction, in which teachers provide all information.

Information Literacy in Problem-Based Learning

Key to PBL is information literacy, defined as the ability to find and evaluate information, reorganize and synthesize information into knowledge, and leverage this knowledge in practice (Moselen & Wang, 2014; Walsh, 2014). In the process of searching for information and creating claims, students are encouraged to have ownership of their learning and develop their own plan to solve the problems (Diekema, Holliday, & Leary, 2011). However, students often struggle to find and utilize information for problem-solving due to poor information literacy and an overwhelming amount of accessible information (Dodd, 2007; Macklin, 2001). Providing a systematic process by which students can identify what they already know and should need to know to utilize and evaluate information for problem-solving is required for successful PBL (Snavely, 2004). Despite the importance of information literacy in PBL, information literacy has not been considered an important ability required for successful PBL (Diekema et al., 2011). In addition, there has been a lack of studies about how information literacy can improve and affect students' development of appropriate solutions in PBL.

Argumentation skills in Problem-based Learning

PBL problems are not intended to serve as vehicles to evaluate students' knowledge and abilities, but rather as contexts around which students can construct knowledge (Uden & Beaumont, 2006). Therefore, students need argumentation skills, defined as the ability to make claims supporting a solution based on appropriate evidence (Kuhn, 1993; Means & Voss, 1996; Toulmin, 1958). In fact, science has been developed through controversy, conflict, and discussion rather than general agreement (Kuhn, 1993) and persuasive argumentation based on reasonable evidence can play a pivotal role in this process. However, students often struggle to develop argumentation skills (Ge & Land, 2004). The first difficulty in PBL happens while students try to represent ill-structured problems. Students need to understand and define the problems because not all information required to solve the problems is included (Jonassen, Howland, Moore, & Marra, 2003). Students tend to define and represent problems superficially when first encountering a problem situation (Jonassen et al., 2003). Next, students struggle to devise a solution. Students often lack the domain and structural knowledge required to develop solutions, and it is difficult for students to understand problems, gather evidence, and develop appropriate solutions (Jonassen, 1997; Ge & Land, 2004). Therefore, students have trouble developing argumentation skills due to insufficient skills about what they know and need to know, where the origin of information is, and how they analyze and justify knowledge.

Additive Effects of Two Skills

Students' activities in PBL are largely divided into two sections – a) problem discovery and b) problem management (Barrows & Tamblyn, 1980). In the problem discovery section, one searches for, evaluates, and utilizes information. Problem management involves determining and synthesizing evidence for making claims as well as linking the evidence to claims in order to address the problem. In other words, to fully understand how students address PBL problems, one needs to consider information literacy and argumentation skills together (Barrows, 1986). However, it is unclear how these two skills should be balanced and emphasized at each step of PBL because there have been few studies considering the effects of each skill in PBL. Addressing this issue can be important because the role of information literacy in PBL has actually been underestimated compared to argumentation skills (Macklin, 2001). Moreover, understanding how students with different levels of information literacy and argumentation skill engage in problem-solving process in PBL is crucial when determining what is to be emphasized to help students proceed in learning through PBL.

Scaffolding for Improving Two Skills

Scaffolding is one solution to the dilemma of how to help students succeed when confronted with complex, ill-structured tasks (Hmelo-Silver, Duncan, & Chinn, 2007). Scaffolding was originally defined as "the process that enables a child or novice to solve a problem, carry out a task or achieve a goal, which would be beyond his unassisted efforts" (Wood, Bruner, & Ross, 1976, p. 90). Scaffolding is conceptual, metacognitive, procedural and motivational support that (a) provides temporary help and structure to students while engaging in PBL (Belland, 2014; Hannafin, Land, & Oliver, 1999), and (b) allows students to gain higher-order thinking skills such as problem-solving skills, deep understanding of content, and argumentation skills (Hsu et al, 2015; Savery, 2015). For the past few decades, there has been a proliferation of many new types of computer-based scaffolds to improve information literacy and argumentation skills. Dynamic feedback during the information searching stage helped students identify needed information for problem-solving (Revelle et al., 2002). Providing questions and prompting, which were designed to help students search, validate, and utilize information, played a role in improving their problem-solving skills in ill-structured scientific tasks (Wiley et al., 2009). Web-based scaffolding can enhance students' information literacy as providing the effective searching strategies (Walton & Archer, 2004). An online asynchronous forum supported by scaffolding allowed students to reflect on peers' arguments and to build their own strategy for constructing their own arguments (Lin, Hong, & Lawrenz, 2012). Argumentation through constraint-based scaffolding helped the students to generate alternative hypotheses and justify their arguments in the hypothesis and it positively affects students' problem-solving process (Oh & Jonassen, 2007). The above examples demonstrated the effectiveness of computer-based scaffolding on two skills. However, due to a lack of studies, which demonstrated the effect of computer-based scaffolding on information literacy and argumentation skills in the context of PBL, more work to directly investigate the effect of computer-based scaffolding in PBL is needed.

Virtual Field Trips in Problem-based Learning

Students need to contextualize the problematic situation through direct experience with real samples because the tasks in PBL have no one right answer and require students' exploration in authentic learning contexts (Chan, Ho, Chan, & Sin, 2005). One way to provide such opportunity for direct experience in authentic environments is through field trips to authentic settings (Clinton, 2015). Incorporating field trips in science education can lead to the following benefits: improved recall of scientific knowledge (Miglietta, Belmonte, & Boero, 2008), higher achievements (Falk & Needham, 2011), and more positive attitudes towards science (Nadelson & Jordan, 2012). However, incorporating field trips poses financial, time burdens and safety challenges (Lewis, 2008).

To counter these challenges, one can employ Virtual Field Trip (VFT), defined as out-of-school activities and computer-generated environments to allow students to virtually visit a certain place for the purpose of learning without ever leaving the classrooms (Adedokun, Liu, Parker, & Burgess, 2014). VFT can provide a virtual environment to facilitate students' interaction in learning communities (Cassady & Mullen, 2006). It can also be an interrelated archive to provide multimedia resources (e.g., image, video, and even text) as contextual learning materials related to the purpose of learning (Cox & Su, 2004). Arrowsmith, Counihan, and McGreevy (2005) demonstrated the effectiveness of VFT to enable learner-centered exploration and constructive learning by creating learning contexts where students are able to learn by empirical experience. Moreover, VFT can offer much insight about the diversity of landscape and the data, and it can lead to improving students' learning ability as providing various perspectives and expression about natural phenomena (Moore & Gerrard, 2002). Until recently, developing VFT was very costly. For this reason, there have been few studies to develop and test VFT in PBL although scholars fully recognize the importance of direct experience in science education.

Based on the review of literature, a few questions are left- a) Is computer-based scaffolding still effective at improving high-school students' information literacy and argumentation skills in PBL for science education? and b) What is the influence of information literacy and argumentation skill on problem-solving in PBL? This study utilized VFT and a scaffolding system, named the *Connection Log*, to enhance 10th and 11th-grade students' information literacy and argumentation skills. The purpose of this study is to investigate the effectiveness of these scaffolds on information literacy and argumentation skills and to investigate how different levels of these skills affect high school students' problem-solving process.

Research Questions

This study addresses the following research questions:

1. a) Do high school students' information literacy scores increase through computer-based scaffolding supporting student' ability to find, evaluate, and utilize information in PBL?

   b) In what ways do high school students describe computer-based scaffolding as changing their information literacy in problem-based learning?

2. a) Do high school students' argumentation skill scores increase through computer-based scaffolding supporting students' creation and evidence of claims about solutions of scientific phenomenon in PBL?

   b) In what ways do high school students describe computer-based scaffolding as changing their argumentation skills in problem-based learning?

3. How do high school students of varying information literacy and argumentation skill levels experience the problem-solving process in problem-based learning?

Method

Participants

Participants were twenty-nine students who had just finished the 10th and 11th grade and who were enrolled in a summer credit recovery course on environmental science in a public school in the Intermountain West. Participants were assigned into groups consisting of 3-4 students for PBL activities. Each group addressed the central problem from the perspective of a unique stakeholder (e.g., environmentalists, asthma sufferers, government officers, and common citizens). The teacher had 20 years of experience teaching high school science.

Design

This study incorporated a mixed method approach (see Table 1; Onwuegbuzie & Leech, 2006). A detailed description is presented in the section of “Sampling Strategy”.

Table 1

Research Questions, Design, Measurement, and Analysis

Research Questions	Research Design	Measurement	Analysis methods
RQ 1, RQ 2	QUANT→ QUAL	Information literacy test, Argumentation skills test	Wilcoxon Signed-Ranks Test
		Interview, two kinds of observation	Open and axial coding (Strauss & Corbin, 1994)
RQ 3	QUAL	Interview, two kinds of observation	Open & axial coding (Strauss & Corbin, 1994)

Sampling Strategy

This study adopted the sequential design for mixed research methods. The sequential design is utilized in situations where the quantitative and qualitative research occurred sequentially (Onwuegbuzie & Collins, 2007). The participants can be categorized into extreme cases based on quantitative measures, and then the characteristics of each group can be ascertained by the qualitative data according to the purpose of research. The purpose of this study is to figure out whether computer-based scaffolding can positively impact on students' information literacy and argumentation skills by quantitative research, and then to qualitatively investigate how differently students experienced computer-based scaffolding and problem-solving process in PBL according to the different levels of information literacy and argumentation skills, which were first identified from quantitative research. Therefore, the sequential approach is suitable for this study as it assessed the effects of computer-based scaffolding using information literacy and argumentation skills test scores, followed by interview data collected from students whose information literacy and argumentation skills were enhanced or decreased for RQs 1 & 2. Moreover, the quantitative results were also used to regroup students to address RQ3. For RQ3, students are regrouped into four groups by maximum variation sampling using a change of their ranking in the information literacy and argumentation skills pre-and post-tests. One group (n=3) consisted of students who had the highest level of information literacy and the lowest level of argumentation skills. Another group (n=3) consisted of students who had the highest level of argumentation skills and the lowest level of information literacy. The third group (n=3) consisted of students who had the highest level of both skills. The last group (n=2) consisted of students who had the lowest level of both skills.

Materials

Read It More *(RIM)*. *RIM* is a web-based instructional tool that helps students gain information literacy while engaging in a virtual field trip to collect real data on air quality from different locations as shown in Figure 1. In *RIM*, students (a) are presented with an ill-structured/authentic problem that allowed them to devise multiple solutions to bad air quality in their local city (see Figure 2), (b) can read an air quality vocabulary list and air quality study guide, and (c) engage with an animated tutorial (‘HeLIOS') that helps identify which information students need to find and find the information. After accomplishing the basic steps, students started to explore air quality across cities in a Virtual Field Trip (VFT). VFT provided real-world environments of several cities using ‘Google street view’, and students in VFT could explore and analyze the surrounding topography, related facilities, and natural environments of the place where they chose and walked around. In addition, there was a function to measure real-time air quality, and students could check air pollution levels in the desired position. With this tool, students directly compared the air quality from several cities with specific data on air quality components (e.g., Ozone, Co2, No2, and PM2.5, 10). For example, students could measure air quality in Houston, famous for its oil refineries that contribute to air pollution, in VFT. Then, they could choose another city that has a similar Air Pollution Index (API) to that of Houston, but different values for the components within the API. Through this, they could understand the concept of air quality and identify the main cause of air pollution in a certain city through comparison of components influencing air quality in one city and another by searching for and analyzing the related information on internet resources.

However, although students could obtain basic knowledge about air quality and measure the air quality of different cities, they still need assistance selecting the most appropriate sources and analyzing the central problem. To address this issue, *RIM* provided several forms of scaffolding including hints, questions, and feedback that supported students at cognitive and metacognitive levels (Appendix A). For example, while measuring CO, the following scaffolding message can be provided to study CO with the various aspects: “Car exhaust fumes are known as one of the main sources of CO. Based on your measurement of CO, can you tell whether high CO in your local city is due to a large number of vehicles? Is there another reason for high CO levels? Please show your evidence.”

Figure 1. Virtual Field Trips: New York city.

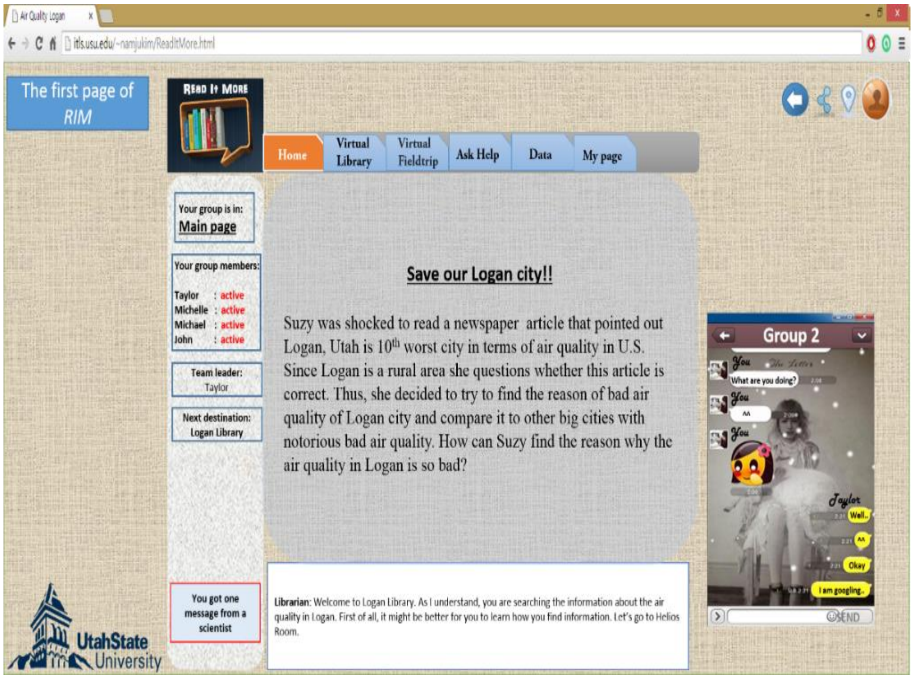


Figure 2. The task in PBL.

Connection Log. The *Connection Log* was used to support students' creation and support of claims about solutions of scientific phenomenon in PBL through individual and cooperative learning activities (see Figure 3) (Belland, 2008) and consists of five stages: a) define the problem, b) determine needed information, c) find and organize needed information, d) develop claims, and e) link evidence to claim (Belland, Gu, Armbrust, & Cook, 2015).

Students can check the progress of their group work and diagnose justification of information through consensus. Every activity requires that group members come to a consensus. In this way, the *Connection Log* can facilitate students' self-directed learning and cooperative learning. One student within each group serves as scribe, organizing information and claims from group members in the *Connection Log*.

Figure 3. Screen shot of the *Connection Log*

In addition, the *Connection Log* provides task-supportive and self-reflective scaffolding. In the case of task-supportive scaffolding, it presents the procedural framework of PBL to support students to find, analyze, and justify their information, select evidence, and evaluate the justification of their evidence through group members' consensus. The *Connection Log* also invites students to reflect on their learning process. The interaction between group members in the *Connection Log* helps students reflect on what the learning goal is, whether their learning process is ideal and if their evidence is reasonable through group discourse. Therefore, the *Connection Log* can provide support and prompts to assist students in getting information to effectively solve the problems and to reflect on their problem-solving process.

How the Materials Were Used

First, within RIM, students (a) learned important air quality indicators (e.g., Ozone, CO2, NO2, PM10, SO2, and so on) and (b) read the air pollution index (API) in different cities and analyzed the causes of bad air quality in those cities. By comparing the provided air quality data with data from their local city, they could further understand air quality in their own city. After finishing data gathering, they moved to the *Connection Log*. A unique stakeholder position was assigned to each group, and students argued the air quality issues from the perspective of their stakeholder. Stakeholder positions included environmentalists, common citizens in a local city, State government, asthma sufferers, and meteorologists. Groups followed the argument creation process supported by the *Connection Log* (i.e., Defining problems, determining needed information, Finding and organizing needed information, developing claims, and linking evidence to claim). Finally, students needed to explain how their solution can improve air quality. Students could iterate the process of gathering and evaluating information in *RIM*.

Data Collection

Quantitative Measures

Pre and post information literacy assessment. This study employed a pretest and posttest on information literacy. Tools for Real-Time Assessment of Information Literacy Skills (TRAILS) were used to assess high school students' information literacy (Kovalik, Yutzey, & Piazza, 2012). The items were created based on information literacy standards from the American Association of School Librarians and the Ohio Academic Content Standards (Voelker, Schloman, & Gedeon, 2013). TRAILS measures students' abilities to conduct the following five processes- a) develop a topic, b) develop, use, and revise a search strategy, c) evaluate sources and information, d) identify potential source, and e) recognize how to use the information responsibly, ethically, and legally (see

Appendix B, C; Schloman & Gedeon, 2007). There are 25 items from across all five categories for pre and post-tests. The maximum possible score is 25 by summing the points from each item. Five school librarians and ten 12th grade classroom teachers positively rated the extent to which the items can actually measure students' information literacy (79.4%-"yes" and 15.57%- "yes with revision") (Salem, 2014). Several empirical studies demonstrated high reliability of TRAILS test scores (Cronbach's alpha from .81 to .82) among high school students (Arnone, Small, & Reynolds, 2010). However, I did not perform reliability analysis of TRAILS in this study due to the small number of participants (n= 29). If the number of participants is under 30, the reliability analysis can be seen as not meaningful due to the unstable component patterns (Yurdugül, 2008).

Pre and post argumentation skills test. To assess argumentation skills, students took an argumentation skills test before and after the PBL unit. Students were given a set of information retrieved from the Internet about the effectiveness of electric vehicles on the improvement of air quality. And then they were asked to make an argument about whether widespread use of electric vehicles can lead to improved air quality (see Appendix D). Argument quality was assessed using the rubric developed by McNeill, Lizotte, Krajcik, & Marx (2006), which divided students' argumentation into claims, evidence, and reasoning (see Appendix E). In previous research evaluating the construction of students' scientific explanation, the scores from this rubric yielded an acceptable reliability (Cronbach's alpha = 0.81; McNeill & Krajcik, 2006). Each criterion has a numerical score from 0 to 2, and the maximum possible score is 6. Each student's score was calculated by summing the points obtained from each argumentation category (i.e., claims, evidence, and reasoning). The individual written reports were scored by two independent raters, using the scoring rubric. Cohen's Kappa statistic was used to measure the initial inter-rater reliability. The results were Kappa = 0.86 with $p < .05$, and this means that there was substantial agreement between raters' scores (Landis & Koch, 1977).

Qualitative Measures

Interview on problem-solving process and experience of computer-based scaffolding. The 30-minute interview was designed to investigate students' own experience in the problem-solving process in PBL as well as to identify the effect of computer-based scaffolding on their information literacy and argumentation skills in detail. The interview questions consisted of two sections: a) information literacy and b) argumentation skills. In the section for information literacy, I asked students a) about their information use, search strategies, and justification of information (information literacy) during PBL and b) what influence their information literacy had their problem-solving process. The second section was related to a) students' argumentation skills - making claims, using information to make claims, and connecting claims to evidence and b) the effects of computer-based scaffolding on their argumentation skills and problem-solving process (see Appendix F).

Observations. In this study, I gathered two types of observations. First, qualitative subsamples of students' activities within PBL in the classroom were videotaped and transcribed. Second, all screen and audio activities on students' computers were recorded to observe their learning process in detail in *RIM* and

Connection Log using *Screencastify*. These two types of observation can be used to (a) identify students' nonverbal expression while using computer-based scaffolding, (b) determine their unique problem-solving approach, and (c) examine their enacted information literacy and argumentation skills.

Log data. In addition to interview and observation data, I also utilized students' notes from the log files while using *Virtual Field Trips* and *Connection Log.* Students' notes gave an additional perspective on the quality of students' information literacy and arguments and contributed to the trustworthiness of the interpretation of interview and observation data. When I interpreted interviews, I consistently checked the consistency between my interpretation and the existing data (i.e., observation and students' notes). I abandoned inconsistent interpretations.

Procedure

All students responded to the information literacy questionnaire and argumentation skills test before beginning the unit. On Day 1, a virtual librarian explained to students what information is, how information is gathered and evaluated, and how information can be utilized for problem-solving. Students were assigned into small groups consisting of 3-4 members. On Day 2, students were presented with the central problem. In addition, a virtual scientist explained the importance of air quality and the factors influencing air quality. And a virtual librarian clarified the unit procedure of *RIM* and *Connection Log.* On Days 3-5, students searched for information related to air quality in a virtual library and gathered real data regarding air quality in their local city and other cities in a virtual field trip. All information and data they collected were in turn used as the evidence of their solution for the air quality in the *Connection Log*. Therefore, the information and data, which were typed in *RIM*, were provided in a paper-based format to students to reduce the inconvenience of revisiting *RIM*. On Days 6-11 students analyzed their data and constructed arguments in *the Connection Log.* Students re-defined the problem and considered the factors that influence on air quality in their local city through compassion with components of air quality from other cities. And then, they presented evidence-based solutions for air quality issues in their local city from their stakeholder perspectives. Through group discussion, students modified and finalized their solutions. Next, all students completed a posttest on information literacy and argumentation skills.

Data Analysis

Quantitative Analysis

Given that the number of participants was so small (n = 29), it was difficult to satisfy the assumption of a normal distribution. Therefore, the Wilcoxon Signed-Ranks Test was used. The purpose of Wilcoxon Signed-Ranks Test is to investigate whether the median difference between pairs of observations is zero (Sheskin, 2003). The scales of the information literacy and argumentation skills tests were interval level, which satisfied the assumption of non-parametric analysis (Sheskin, 2003).

Qualitative Analysis

Theoretical framework. All qualitative data was analyzed through the lens of phenomenography. Phenomenography can be used to investigate variation in meaning, understanding, and conception in early days (Marton, 1986), but it has been recently expanded to explore the ways of experiencing a certain phenomenon (Akerlind, 2005; Marton & Booth, 1997). Considering research questions, the phenomenographic approach might address the full range of different ways high school students utilize computer-based scaffolding to improve their information literacy and argumentation skills and experience the problem-solving process in PBL.

Analysis process. The general output of phenomenography is "categories of description," in which text segments from transcriptions can be grouped and regrouped according to differences and similarities (Akerlind, 2005; Marton, 1986). The biggest difference between analysis processes incorporating a phenomenography lens and those incorporating other theoretical lenses (e.g., grounded theory) is that there is not a core category that highlights the main phenomenon and integrates all other categories in phenomenography. Each category itself represents the variation of experience within the group, and the focus is on relationships between categories, not on the integration of categories (Akerlind, 2005; Berglund, 2006). In this sense, the analysis process, which has been commonly utilized across phenomenographic research, is as follows – "Investigating the data", "initial codes and categories", "revising coding schemes", "testing final coding schemes in the final data", and "description of categories through similarity and difference between categories" (Bowden et al., 1992; Kinnunen & Simon, 2012; Marton, Watkins, & Tang, 1997; Vermunt, 1996).

Two graduate students who were experienced in the qualitative research and data analysis participated in the above-mentioned analysis process. The second coder was not familiar with several concepts (e.g., scaffolding, information literacy, argumentation skills, and problem-based learning) in this study and phenomenographic approach. Therefore, the second coder was trained to enhance the understanding of learning contexts in this study and to develop the coding structure.

For the first step, two coders looked over interview transcripts and observation protocols in order to identify whether there is enough data to represent a) the impacts of multiple sources of computer-based scaffolding on each student's information literacy and argumentation skills and b) the variation of students' experience in problem-solving process supported by computer-based scaffolding according to their level of information literacy and argumentation skills. This round allowed two coders to familiarize myself with the data.

In the second step, coding scheme was initially informed by previous theoretical literature and the factors/steps embedded in VFT and *Connection Log*. Words or paragraphs reflecting a certain meaning and idea were selected to generate codes. For example, there were 21 codes related to "information searching", "information evaluation", and "information utilization" included for analyzing student's information literacy and 16 codes reflecting students' "problem-management", "generating claims", and "linking evidence to claims" related to argumentation skills. There were also 13 codes for computer-based scaffolding added to describe students' experience in using computer-based scaffolding to improve information literacy and argumentation skills. These coding scheme and the initial codes were generated by two coders' consensus through discussion. The inter-rater reliability between the coders (Krippendorff's alpha =

0.82) about the initial codes was above the minimally acceptable level ($\alpha = 0.667$, Krippendorff, 2004)). After generating a list of initial codes, I conducted axial coding, in which individual codes were clustered together into overarching categories.

In the third step, the codes and categories developed by open and axial coding were verified by several review processes from multiple data sources, resulting in confirmation, replacement, and termination. For example, if the category “computer-based scaffolding as the effective means to improve information literacy and argumentation skills” was described, this description was compared to the results of students’ arguments and the log files (i.e., students’ notes) in the VFT and *Connection Log* to see whether the generated category was consistent across the multiple data sources. Based on this process, I finalized the categories (See Table 2). As the last process of analyzing data, I constructed relationships among categories to see what is identical and dissimilar. This relationship between categories can inform me of the variation a) in each student’s ability in terms of information literacy and argumentation skills affected by computer-based scaffolding and b) in each student’s experience in the problem-solving process supported by computer-based scaffolding according to their levels of information literacy and argumentation skills. I checked the verification of each conclusion generated by the relations between categories through the triangulation of various qualitative data and quantitative data. I looked over the students’ screen recordings on VFT and *Connection Log,* the result of quantitative argumentation skills tests, as well as the interview data to investigate if these multiple data sources can support the generated conclusion.

Table 2

Categories generated by the Qualitative Analysis

Students' Experience about Computer-based Scaffolding for Information Literacy
• Category A: Computer-based scaffolding as an effective means to improve information-searching strategies for problem-solving • Category B: Computer-based scaffolding as an effective means to verify the accuracy of information and the data • Category C: Computer-based scaffolding as an obstacle to learning
Students' Experience about Computer-based Scaffolding for Argumentation Skills
• Category A: Computer-based scaffolding as the systemic procedure for organizing evidence and making claims • Category B: Computer-based scaffolding as the complicated procedure to make learning more difficult
Students' Problem-solving Process in Problem-based Learning
• Category A: problem-solving process building knowledge by self-directed Learning and immersion in learning • Category B: problem-solving process revealing a lack of the evidence-based arguments • Category C: problem-solving process revealing a lack of consideration about the importance of information as evidence • Category D: problem-solving process merely aiming to find the right answer

Results

Research Question 1

Quantitative results. The data was not normally distributed, Shapiro-Wilk = 0.89, p < .01. Wilcoxon Signed-Ranks Test indicated that the post-test median was statistically higher than the pre-test median, $Z = 2.818$, $p < .01$, $ES = 0.37$. Twenty of the students' rankings increased according to the information literacy test (see Table 3). This means that computer-based scaffolding had positive effects on 20 of the students' information literacy, whereas only four students fell in ranking. Five of the students' ranking did not change between the pre and post-tests.

Qualitative results. Three categories of students' different experiences in computer-based scaffolding to support information literacy were identified, namely, that computer-based scaffolding was a) an effective means to improve information-searching strategies for problem-solving, b) an effective means to verify the accuracy of information and data, and c) sometimes an obstacle to learning. A description of each category as explained by the quotes of one or two students representing the different groups is included below. The names of students and the local city (i.e., Mountain City) have been replaced with pseudonyms.

Category A: Computer-based scaffolding as an effective means to improve information-searching strategies for problem-solving. The observation by *Screencastify* indicated that students who lacked experience searching for information for educational purposes began by utilizing generalized searching terms like "air quality" while performing Google searches. Students were exposed to too much information, resulting

Table 3

Wilcoxon Signed Ranks Test for Information Literacy

		N	Mean Rank	Sum of Rank	Z	Asymp. Sig (2-tailed)
Pretest-Posttest	Negative Ranks	20^a	13.13	247.50	-2.818	.005
	Positive Ranks	4^b	12.38	52.80		
	Ties	5^c				
	Total	29				

Note. a. Posttest > Pretest, b. Posttest < Pretest, c. Posttest = Pretest, d. Z values based on positive ranks

in difficulty selecting credible information. Computer-based scaffolding in the form of "Hints" and "Question prompts" guided students to determine more specific searching terms and to distinguish reliable from unreliable sources. In addition, students were asked about their judgments about the credibility of the resources from computer-based scaffolding when they found a certain piece of information. In this regard, students recalled that computer-based scaffolding was a great help in finding information quickly and accurately in the following interview asking about their experience with computer-based scaffolding.

> William: You know, the number of my first searching results was about 20,900… I changed the searching terms with help from… How would I say this?...Okay. Computers. And I greatly reduced the results number… Yeah!! Very helpful.

> David: When I searched for information, I remember... The pop up explained the way to search for books. [actual scaffolding on the screen: "When you want to purchase a certain book, how did you search for this book? You probably put the title, publisher, year, authors of this book. Please consider this"]…It was helpful for me to use the specific searching terms for air quality information".

Another student, Elisa, expressed a detailed experience about the effects of computer-based scaffolding on searching for information. Computer-based scaffolding helped her determine the most validated and justified information among conflicting online information sources. Elisa sometimes found conflicting information from internet resources that caused confusion. In the observation of her activities on screen, she had difficulty discovering true knowledge from among such conflicting sources, and it often caused her difficulty in the interpretation of data as mentioning “I didn’t know what to do…so frustrated”.

However, in *Screencastify*, after the scaffolding explained what conflicting information meant and suggested the methods to choose reliable resources, she expressed satisfaction with the scaffolding help, often mentioning that it was “wonderful” and “cool”. The next retrospective interview showed how Elisa established her own strategy to distinguish between right or wrong information.

> Elisa: I was embarrassed when I found two conflicting information [inconsistent information from multiple information sources]. The software [Virtual Field Trips] was cool, it gave me hints and feedback. It helped me realize which information was most reasonable and validated. It didn’t just hand me the answers, it helped me to find the solution. My solution was to search information from the websites with .gov, .org..

As shown in the above example, Elisa followed the support from computer-based scaffolding as she found justified information through her own means, and she developed her reasoning by reconciling the difference between conflicting information due to the scaffolds, which provided the expert procedure of searching for information.

In addition, computer-based scaffolding helped her consider the problematic situation from the perspective of an assigned stakeholder - environmentalists. Through the observation, I could identify that other students in her group just focused on searching for information about air quality issues without considering their stakeholder. Elisa also did not consider her stakeholder perspective at the beginning of the unit; she did not know the exact meaning of the term *stakeholder*. However, after the VFT invited her to summarize and integrate the information she had gathered so far, she recognized the nature of her struggles searching for information. Afterward, her search terms on the screen always included the words like 'environmentalist' and 'the natural environment', which reflected her stakeholder position. The next interview explains how she came to consider her stakeholder perspective.

> Researcher: When you found information, did you consider the perspectives of your stakeholder?
> Elisa: At first I didn't, but when I started to summarize the information I got [the] computer's requesting and all of the information I got said different things. So, I recollected the data with the perspective of environmentalists after I got the computer's requesting.
> Researcher: So was there any benefits to doing that?
> Elisa: Yeah, it made my next job and organizing data so easy. It actually made the whole thing go so fast.

Considering the stakeholder's perspective when searching for information is important as the information found can play a role in finding evidence for the claims to solve problems. As she mentioned, if students utilize information regardless of the stakeholder in the creation of their claims, those claims cannot be validated as a good solution for the given tasks. She recognized this and considered the perspective of her stakeholder when she searched for information. The requests for summarizing the gathered information from the computer-based scaffolding helped her reflect on her searching strategies.

Category B: Computer-based scaffolding as an effective means to verify the accuracy of information and the data. In addition to following an advanced information-searching strategy, accurate verification and interpretation of gathered information are also crucial to success in PBL. However, the air quality of any city is often erratic, and this can lead to students misunderstanding air quality in a certain city, resulting in totally different outcomes when solving air quality issues. If students overlook this issue, their information-searching when solving air quality issues could be limited to exclude air pollution components affecting bad air quality. However, it is difficult to expect this of the students' abilities without any support. Through VFT, which allowed them to gather real air data from various cities, students started analyzing the reason why air quality across the cities was different. In addition, VFT extended to their role in providing scaffolding to students who struggled with finding suitable information and interpreting information they gathered.

Brett expressed the benefits of using scaffolds to justify the data he gathered and to find the proper resources to interpret the air quality data. This was verified by his activities recorded in *Screencasfy*. He thought that the air quality of Orlando was the worst based on the real-time air quality data he measured, and when he put the data into his personal notes, the computer revealed 10 years of data on air quality of Orlando. Examining the data, he discovered that the current air quality readings could just be temporary because Orlando is one of the best cities regarding air quality. The prompts (i.e., the history of air quality) from the scaffolding gave him the opportunity to reflect on the air quality data again and to recognize the possibility of that his data was inaccurate. He used online resources to find information on why Orlando's current air quality is so bad and found that a rocket had been launched from Kennedy Space Center near Orlando at the time of his measurements. During the interview, Brett mentioned that it would be difficult to gather accurate data and to find, assess, and evaluate information for problem-solving without the computer-based supports.

> Researcher: So, can you tell that this software [The virtual field trip] helped you find and use the information?
>
> Brett: Yeah, it helped me to find good information. Information was not too broad but it was good. I used this software to find the air data in Orlando. I thought the air quality in Orlando would be so bad and it was. But a pop-up window came on and it showed Orlando's air quality history. Then I knew the air quality that I found was only temporary… I love this program, it helped me to find accurate air quality data. Without the pop-up window, I would've reported Orlando as the worst air quality city.

This interview excerpt showed how effectively the computer-based scaffolding provided by the Virtual Field Trip assisted Brett's validation of the data and interpretation of the gathered information. Before starting the unit, the observation from *Screencastify* showed that Brett expressed that he was often bored during science class and felt great pressure to learn science, but, in this unit, he was more actively involved than anyone else, and indeed, the information about air quality he collected was well organized and qualified as seen when investigating his note and screen-recording videos.

Category C: Computer-based scaffolding as an obstacle to learning. Many students experienced an improvement in their information literacy through computer-based scaffolding according to the above mentioned two categories. However, some students, whose information literacy did not improve during the unit, regarded the computer-based scaffolding as a hindrance to their learning.

The observation by *Screencastify* indicates that Elizabeth expressed her dissatisfaction openly about using computer-software to investigate air quality of the local city and the learning environments involving self-directed learning as mentioning “I hate this” and “so confusing”. She thought that teacher-led instruction could be more effective and efficient, as noted in this interview passage.

> Elizabeth: It was not the best fit for me. I think the learning was not efficient. The science class I took before, I did not have to gather information. My teacher would explain concepts and I just needed to correct the questions with the handouts. But if you google air quality soooo many things come up and probably more than half of this information would be something that I do not need. There is no way I am going to look over all the information it is just not worth my time and actually even if I find information I would not know if it is the right information to use.
>
> Researcher: So computers could not help you find and evaluate suitable information?
>
> Elizabeth: No, it wasn’t really helpful, it actually slowed me down. On the virtual field trip, things would pop up constantly and it was difficult for me to concentrate on my work. The pop-ups got in the way so I just closed them all.
>
> Researcher: So, you hated these programs, right?
>
> Elizabeth: No it was fun it was just little different
>
> …
>
> Researcher: How did you find your information? Can you explain your information searching process?
>
> Elizabeth: I used Wikipedia
>
> Researcher: So can you believe the information from Wikipedia?
>
> Elizabeth: Everyone uses Wikipedia and it is an encyclopedia; all truth.
>
> Researcher: That means you got all information from Wikipedia and did not consider any other resources?
>
> Elizabeth: I got enough information from Wikipedia, and did not want to use other sites.

As Elizabeth mentioned, she preferred the previous teacher-led instruction to the new approach to science learning. Therefore, the observation of her activities and the log file indicated that she did not pay much attention to enhancing her information-searching skills or justifying the information required for solving the ill-structured problems, which had the various solutions. The information she gathered was never validated through comparison with other resources, but she strongly trusted, without any doubt, the information that she based on her personal experiences. This observation corresponded with her comments in the interview. Computer-based scaffolding was provided to let her know the way of finding multiple sources of consistent information, but she thought that computer-based scaffolding was useless and she denied help by closing the pop-up windows, a form of computer-based scaffolding. This was verified by the observation of her activities as she said: “[I kept] closing the pop-up windows… [they] bother me!!”. This attitude represented her view on computer-based scaffolding - an unnecessary obstacle to quickly finishing her given tasks.

Another student, Kevin, who did not improve from pre to post on the information literacy test, also experienced inconvenience when using software to find information in the following interview.

Researcher:	Kevin, what do you think about using the virtual field trip to get the data and information about air quality?
Kevin:	It was okay but kind of annoying
Researcher:	Why? Were there any technical issues?
Kevin:	No, it’s just that when I got air quality data the software showed me the links to explain stuff that I know already like Ozone, CO2, No2. It was okay for the first time, but whenever I got new data, the same message would show and then it got annoying.
Researcher:	So why did you not request more help? You could stop the existing help and ask for different help.
Kevin:	Really? I did not know that. After then, I just walked around the cities with virtual field trip.

When he first tried to move around several cities to measure and to compare air quality data, he saw that computer-based scaffolding helped with interpreting the data and finding the information necessary for understanding concepts. However, as this similar process was repeated, his motivation and passion for researching data and information decreased. Therefore, he engaged in the off-task behavior. Video records confirmed this in that he seldom tried to find any information about air quality except for the first day and just stuck to visiting the cities.

Research Question 2

Quantitative results. Table 4 shows the number of students who raised their ranking in the argumentation skills test (n = 20), the number of those whose ranking dropped (n = 2), and the number of students with an equal ranking between pre- and post-test (n = 7). The results of Wilcoxon Signed-ranks tests indicated that students who received computer-based scaffolding showed significantly higher achievement in the post-test (Mdn = 3.00) than in the pre-test (Mdn = 2.00) of argumentation skills, $Z = 3.80$, $p < 0.01$, ES=0.50.

Qualitative results. Two categories were identified to analyze the students' different experiences in using computer-based scaffolding for the tasks that required argumentation skills. One category indicated that students recognized computer-based scaffolding as a systemic procedure for organizing evidence and making claims. On the other hand, another category described students' negative opinions about computer-based scaffolding involving a complicated procedure that makes learning more difficult.

Category A: Computer-based scaffolding as a systemic procedure for organizing evidence and making claims. Students experienced self-confidence about the procedure of PBL because the *Connection Log* provided students a basic framework to help them organize their thoughts and to activate their discussion in PBL. A student (i.e., Andrew) gained confidence in how to address air quality issues by easily identifying the

Table 4

Wilcoxon Signed Ranks Test for Argumentation Skills

		N	Mean Rank	Sum of Rank	*Z*	Asymp. Sig (2-tailed)
Pretest-Posttest	Negative Ranks	20^{a}	12.13	242.50	-3.792^{d}	.001
	Positive Ranks	2^{b}	5.25	10.50		
	Ties	7^{c}				
	Total	29				

Note. a. Posttest > Pretest, b. Posttest < Pretest, c. Posttest = Pretest, d. Z value based on positive ranks.

systematic problem-solving process in PBL with the quotes from the observation by *Screencastify*: "just see the examples…not too hard to do", "Now I understand what to do", and "Look what I've done….you cannot move on to the next step until you complete this…". Moreover, students (i.e., Andrew and Ella) could adjust to a new learning environment of PBL without difficulty due to the systematic procedure of PBL that the *Connection Log* provided as they mentioned in the following interview.

Researcher: Are there any difficulties in doing your research in the *Connection Log*?
Andrew: No problems. I just followed the steps and finished.
Ella: Many things to do, but I don't think that it'd be too difficult.

Typically, students perceived that the problem-solving process in PBL was complicated due to a lack of experience in learning by self-directed learning and in applying knowledge to ill-structured tasks. However, Andrew and Ella never complained about the PBL process due to the systemic steps provided by the *Connection Log*.

Jason, whose stakeholder was asthma sufferers and who himself suffered from asthma, strove to connect the given problematic situation into his real life, resulting in increased passion for his problem statements, searching for information, and the creation of claims representing the perspectives of asthma sufferers. This sample from his interview shows his improvement in terms of information utilization to create claims with the help of computer-based scaffolding.

> Researcher: Could you explain how the *Connection Log* helped you make claims with information you gathered?
>
> Jason: It helped me summarize collected information, and organize them effectively.
>
> Researcher: Can you explain in more detail?
>
> Jason: I liked the steps from the *Connection Log* because it made my work easy. Although I think that topic was broad in this case. There are multiple kinds of asthma, I know this because I have asthma, anyway, but air pollution doesn't bother me. But you know, the sufferer would've been more specific [the symptoms and the cause of asthma vary]. I could've found more specific information if types of asthma were narrowed down. When I saw the question "how does the air quality affect my stakeholder?" it got me think more about specific symptoms of asthma…and I think it would be better if we can share our work. The program tells me what I am doing but this is a group work. If I can see other students' work, I can check how my group is doing and compare the information too. A person from my group collected wrong information about asthma and I corrected this because I am an expert in asthma. I think that our group claim could be better through this cooperation.

Jason had prior knowledge about air pollution because he had asthma, and the given tasks were familiar to him. Nevertheless, he mentioned that he did not previously consider how air quality affects specific types of asthma in the interview. However, in the observation, he did define the problem from the perspective of asthma sufferers and focused on searching for information related to asthma as guided by the prompts and procedure from the *Connection Log*. For example, he found that Ozone has a strong influence on asthma, and he also discovered that the number of asthma sufferers rapidly increased as the ozone layer was destroyed in the last 10 years through credible internet resources. The reason he could focus on air quality issues from the perspective of asthma suffers is that the question prompts reminded him of the stakeholder position he needed to determine his problems. Therefore, he believed that if ozone issues are addressed in the local city, the number of asthma patients could be reduced. When discussing group claims, he showed that some claims and evidence were inconsistent with their stakeholder perspective, and he re-assigned additional information to find to group members. Several other data sources (e.g., students' essays, screen video recording, and notes) also indicated that the group he led generated claims with strong evidence about the air quality solution for asthma sufferers.

Evan, who also improved from pre to post in argumentation skills, thought that if he could find better information, then the *Connection Log* would be a very helpful tool to derive better solutions to the given tasks. He especially had followed the introduced approach to science learning by participating actively in the learning process with the *Connection Log* despite having often claimed that learning science was boring. He also mentioned that he learned the importance of validated information in creating more reasonable solutions to the scientific issues. The following interview excerpt shows his experience with the effects of computer-based scaffolding when making his arguments.

> Researcher: How does the *Connection Log* help you make your claims?
> Evan: *Connection Log*?
> Researcher: Yeah, the second program you used.
> Evan: Oh yeah, it was good I liked it. In the *Connection Log* I organized information I gathered. It was very convenient and each step was easy to follow. I enjoyed this learning.
> Researcher: Can you explain more?
> Evan: I've learned that making a good solution totally depends on information. I think that if information is believable, my solution supported by this information can be powerful. I just followed the

> steps in the *Connection Log*, and each step told me what I should do to make a claim.

His opinion about the positive effects of computer-based scaffolding was verified with the following observation data from *Screencastify*. Evan considered possible air quality solutions based on the geography of Mountain City and specifically its worst season, not from just a broad approach to air quality solutions. And he could organize his information well according to the steps *Connection Log* provided. His solution was based on believable and validated evidence and above all, he was confident in his evidence and claims.

Computer-based scaffolding from the *Connection Log* provided general strategic support (i.e., systemic steps of PBL). Therefore, it might be difficult for students to directly describe their experience of computer-based scaffolding with the *Connection Log* because there were no direct supports to solve their current learning issues in this unit. However, based on the students' interview, it is clear that students in this category could experience successful research in organizing the evidence and making claims for solving air quality issues through the systemic steps provided by the *Connection Log*.

Category B: computer-based scaffolding as a complicated procedure to make learning more difficult. This category is contrasted with Category A. Most students improved their ranking on the argumentation skills test, but there were some students who still got the same score or a lower score after finishing the PBL unit. This category shows why computer-based scaffolding might not have been very helpful for those students to improve their argumentation skills based on their experience. Cathy struggled to understand tasks at the beginning of the unit because they required a different learning approach compared to the learning process with which she had already been familiar. In the interviews, she often mentioned "[she] did not know what to do" or "[was] frustrated". Actually, in the observation from *Screencastify*, she did not use the *Connection Log* much, and just passed through the steps without any writing any entries. If the *Connection Log* showed an error message due to no entry, she tended to react emotionally. The following interview excerpt indicates a lack of argumentation skills during her experience in using *Connection Lo*g.

> Researcher: Okay. How did you use the *Connection Log*?
> Cathy: Too complicated.
> Researcher: What do you mean "complicated"
> Cathy: There were so many things to do, and I was a little tired because it kept requesting me to do similar things.
> Researcher: So, you think that each step in the *Connection Log* is similar?
> Cathy: Yeah, I think so and I didn't know how to do them.
> Researcher: Why did not you see the example explaining about how to do or ask me and your group members?
> Cathy: Just annoying.

She made a frank confession that she did not understand what and how to do in the *Connection Log*. She never paid attention to prompts to help students identify the requirement of each step because she thought that the procedure was complicated and repetitive. This contributed to her development of poor quality claims, which were not linked to any evidence. Her final claim identified by *Screencastify* and the log file was "Want to eat Pizza", which was not relevant to the given topic at all. This can be explained by her reluctance to learning science and that there were relatively more tasks compared to the traditional teacher-led instruction rather than to the effects of the *Connection Log* because the sentences she mentioned mostly in the interview were "I hate Science", and "so much to do".

Charles also pointed out problems in the procedure of making the claims, especially group work, in the interviews.

> Researcher: What do you think about the *Connection Log*?
> Charles: Not fun…whenever I finished my work, I was asked to come together into scribe's computer. But actually, we didn't. She [A scribe] did all the work…we did not do anything at that time….a waste of time…I didn't understand why we should do that… We didn't know what she did….I didn't know how to handle the errors…As for me, difficult to finish my work.

He did not experience the advantages of group work in the *Connection Log* because he perceived that the group work could not be beneficial for his learning. Because he did not concentrate on the group work, he could not well understand the following tasks after the group work from the observation, and it made it hard for him to finish his work successfully in the *Connection Log*.

In summary, most students generated good quality claims with sufficient evidence for solving air quality issues through the systematic procedure from the *Connection Log*. However, a few students who were not interested in learning on a basic level or who regarded the systemic procedure from the Connection Log as just complicated experienced poor learning performance in the *Connection Log*.

Research Question 3

Students of differing information literacy and argumentation abilities experienced different problem-solving process in PBL. These experiences can be divided into four categories- a) building knowledge by self-directed learning and immersion in learning, b) revealing a lack of the evidence-based arguments, c) revealing a lack of consideration about the importance of information as evidence, and d) merely aiming to find the right answer.

Category A: Problem-solving process building knowledge by self-directed learning and immersion in learning. All students who experienced the problem-solving process in this category had high information literacy and argumentation skills based on the results of pre and posttests. The distinctive characteristic of these students is that they effectively searched for and explained the information by independent work or active interaction with group members and internalized the knowledge through a process of summarizing and evaluating the information. In addition, in the observation of their activities on *Screencastify*, they showed an attitude and willingness to draw the conclusions voluntarily and proactively in order to exert self-directed learning skills. This means that students in this group actively and effectively engaged in scientific inquiry, as illustrated in the following quotes from the interview.

Julie: I was lost. I was confused and did not know where to start. The questions do not have any correct answers. I don't even know how I got out of confusion but computers helped a lot. I liked it because I didn't have to bother anyone, I could do everything by myself… I could deal with various sources about air quality. After gathering information, I just choose the top information whenever I gather new information and change an unsatisfied thing into the down [referring to organizing information by the student's criteria with her most valued information at the top of her list and her least valued at the bottom]. After all, I can check all of my information for problem-solving at a glance. In the *Connection Log*, I could easily do my work [making the claims] with evidence.

Alex: When I walked into the class I thought I would be working on a regular group project. You know just get together maybe make pretty posters some work hard and some don't…but this was different I had to participate and pay attention to gather information for myself and team members. Everything was really interesting like gathering information, making my own solutions. Save Mountain City!!

Thomas: I wish all of my classes use this software. I learned so much about the air quality and other related stuff like Ozone, No2, Co2. Ask me about these I could explain… It was fun to look at my group members' information and claims. Their claims were really similar, but information they gathered was totally different. I totally felt the importance of information… Now I am a pretty good problem solver

All students in this group seemed to adjust well to the PBL procedure and to understand the purpose of PBL. Julie could identify the importance of information, which plays a role in establishing evidence for claims. In other words, she realized what she knew and should know for making a creative solution to the air quality issues, resulting in advanced information-searching strategies. The observation of her activities supports her advanced problem-solving process. For example, she rearranged information she gathered in order of importance and successfully linked the selected information as evidence to her specific claims. Alex emphasized ownership of his learning and the effectiveness of group working. He experienced the joy of self-discovering new scientific knowledge as mentioning "I found this!!" and "this information is really interesting" and the fact that group work could lead to the generation of strong evidence and claims. In the case of Thomas, the advanced problem-solving process in PBL enhanced his content knowledge about air quality as well as motivating his passion toward his learning. In addition, he realized how important the accomplishment of each task from steps in PBL was to obtaining more logical and reasonable conclusion than otherwise as he experienced the different quality of outcomes, depending on how well each task in the whole section was completed.

Category B: Problem-solving process revealing a lack of evidence-based arguments. Students in this group had high information literacy and low argumentation skill gains from the pre to post-tests. They were certainly aware of what they knew and what they needed to know. Therefore, they collected reasonable and validated information related to their problematic situation from the perspective of their stakeholders. However, their abilities to utilize and organize information as evidence of their claims varied from those of students in category A. For example, the screen recording by *Screencastify* showed that Julie (category A) and Elliot (category B), who each represented the same stakeholder (i.e., common citizen), gathered a similar amount and quality of information from the same resources, and their claims (i.e., increasing the number of electric vehicles) were also very similar. However, the quality of their final notes, which restated the final claims with evidence, was not identical due to the different level of argumentation skills even though both students had a high level of information literacy. The following claims from two students' notes show the difference in the quality of the two arguments.

Julie (category A): It is really difficult to get rid of the pollution in Mountain City, so the only way we can make it better is by getting rid of bad habits. If we drove less, and rode bikes or converted entirely to electric cars it would send less CO SO2 NO2 PM2.5 and PM10. These are all unhealthy things, it's not something you would want your kids or babies to be breathing in. Our air quality can only get worse, we could slow down the process by shifting to healthier alternatives and "being green". The biggest way we can slow down this process is by converting to electric cars and turning to alternate energy sources. Once we master these cars it will get less expensive, we should start by banning gas driven cars and making it an actual law, then provide alternative energy source transportation for the people who can't afford electric cars yet. There are not big air pollutants in Mountain City, and I think this method will work.

Elliot (category B): Some of the biggest problems with air pollution in Mountain City are cars and the burning of fossil-fuels. They release toxic chemicals into the air such as CO and CO_2. This greenhouse gas is contributing to global warming and that is harming the environment in its own way. Some ways to combat this is taking public transportation with electric systems or the electric cars. If we work together we can stop pollution for good.

Both examples suggest the usage of electric vehicles as the solution for reducing air pollution. And it is clear that much information should be collected properly to make these arguments. Julie analyzed the problematic situation, organized information very well, and linked the information as the evidence to her claims. However, in the case of Elliot, the evidence was not consistent, and it is difficult to say that his evidence supported his claim very well. This means that a high level of information literacy is not enough to guarantee good argumentation skills and success in PBL. Students in this group expressed the difficulty of making claims with their gathered information in the interview.

Elliot: I could collect a variety of data and information in addition to the existing knowledge I knew. There were so many resources needed to solve the problems. It was necessary to think of any issue with the various ways…so difficult to remove the unrelated information and to select some information for making a claim. I think that all information is important…I thought that selected information cannot support my claims very well.

Alex: The claims, I mean, we didn't have much time to do a lot of research. So it was like, okay, you read a few and pick the best one that has the most information, stick it in there and go with it. We had time, you know, 3 or 4 pieces our information in piece, you can make better claims because rather than having 3 articles, you have 12 articles.

Tyler: Have you tried it? It's really fun to walk around cities to gather air quality data. I think I learned something new. Time just flew by. But the very last step was kind of boring… I don't know. Just boring.

The likeness between them is that they felt interested in gathering the data, searching for information, and analyzing information. However, their interest did not last very long. They struggled with organization and utilization of information as evidence of their claims. That is, they could not make their information fit together, and the evidence linked to their claims was sometimes not well-organized.

Category C: Problem-solving process revealing a lack of consideration about the importance of information as evidence. This group consists of students who scored low on information literacy and high on argumentation skills throughout the pre and posttests. Interestingly, the quality of their final arguments was similar to that of Group 1, which scored high on information literacy and argumentation skills. This could indicate that information literacy does not influence students' problem-solving in PBL as much as argumentation skills do. However, Debra's interview revealed that well-organized evidence for the claims was obtained from group members, not from her own work.

> Debra: Because I was a group leader I could check other members' information and their claims. And I borrowed some information that I thought was really good… I don't think I did anything wrong since I made my own claim I just used other people's information... We worked together.

She explained her activities related to information literacy as collaborative learning. The collaborative process in PBL has the positive effect of increasing understanding of the problem, elaborating their evidence as sharing the sufficient information, and better engagement through the active interaction. However, the screen-recording video from *Screencastify* demonstrated a lack of information literacy for her. She may not constitute collaborative learning because she just borrowed the group members' work without any discussion and interaction. This means that she did not have any opportunity to experience the sophisticated procedure of searching for, justifying, evaluating, and utilizing the information. Nevertheless, her claims were well-supported by the justified evidence from the group members due to her advanced argumentation skills. For example, her claim was “we should ban the use of wood stoves [wood-burning stoves] to protect Mountain City’s air” supported by the following evidence- a) the data of Mountain City’s air quality index deteriorated rapidly in winter, b) the statistics showing that the north intermountain area is the place that uses wood-burning stoves most frequently, and c) Mexico’s experience solving their air pollution by the reducing the use of wood-burning stoves. When considering the quality of her final claim and evidence supporting his claim, it seemed to be qualified. However, based on the observation she just used her groupmates' information and evidence, and she could not identify whether group members’ information was valuable. Assuming a situation where there are no group members to provide her evidence or there are only group members who have a low quality of evidence, she may have had a difficult time finding the validated information from credible resources, resulting in a low quality of claims. Therefore, her case indicates that advanced argumentation skills without considering the importance of information as evidence cannot guarantee the successful learning performance in PBL.

Category D: Problem-solving process merely aiming to find the right answer. The students in this group had low gains from pre to posttests of both information literacy and argumentation skills. This group’s case shows how difficult this kind of students successfully accomplished the ill-structured tasks in PBL. In the observation, they just tried to find the right answer as soon as possible as they did in the teacher-led instruction, and they did not gather information from a variety of sources or evaluate information at all. One piece of information, which a researcher provided as an example source, was only the only one utilized as the evidence for their claim. From their perspective, PBL seemed to be the easiest learning approach. Actually, they always finished their days' worth of work within 20 minutes even though other group members often complained about the limited learning time, and they often engaged in off-task behavior or hindered the group members in their learning.

When Mickey defined the problem, she did not consider the perspective of stakeholder and kept asking, "what is our stakeholder?". On the screen recording, her problem statement was "Mountain City's air quality is so serious" without any deep thoughts about "what is happening?", "who is it affecting?", and "how it affects them?", which the *Connection Log* requested. Because she did not think about several factors (i.e., stakeholder, problematic situation, and systematic steps in the *Connection Log*), which can largely affect the quality of their final products, the claim could not be supported by relevant evidence. However, ironically, her experience in the PBL process was very positive although she maintained an insincere attitude throughout the PBL units as no one critiqued her learning process, as the interview below shows.

Researcher: What do you think about the procedure of making your claims. Was it complicated?

Mickey: Well. Not really. I was a little bit confused about the software [the *Connection Log*] at the beginning. But I read the questions from the computer [the *Connection Log*] over and over again to figure it out. And then, it was easy to finish the tasks… No problems. The whole thing was really interesting.

It is clear that Mickey could not successfully accomplish the given tasks by self-directed learning and critical thinking.

In contrast to Mickey, Charles outwardly engaged in the individual and group learning activities in the *Connection Log*. However, he did not know efficient strategies to utilize information for problem-solving and to make claims through the proposed learning procedure. In other words, he could not understand the systemic relation between each step, rather he just regarded each step of the tasks as independent. The mission of top priority facing Charles was to just finish each task as soon as possible and to move to the next step. He never concerned himself with how effectively information can be gathered, integrated, and utilized, as well as how the creative solutions to air quality issues can be generated based on how well-organized his information is. The observation from *Screencastify* demonstrated this with the evidence: "I cannot remember my information…I discarded my information because of useless [in the section of 'develop claims']… I do not know why information was necessary for making the claims."

Discussion

This study investigated the effects of computer-based scaffolding on information literacy and argumentation skills in PBL for science education. Furthermore, the diverse problem-solving processes employed by students with varying levels of information literacy and argumentation skills in PBL were identified. In what follows, the primary findings and corresponding implications are discussed.

The Effects on Information Literacy and Argumentation Skills

An interesting finding in the study was the impact of computer-based scaffolding on students' information literacy and argumentation skills in PBL, a finding that is consistent with the literature (Ge & Land, 2004; Revelle et al., 2002; Wiley et al., 2009). Computer-based scaffolding significantly enhanced students' ability to find, evaluate, and utilize information (Theng, Lee, Patinadan, & Foo, 2015; Walton & Archer, 2004). In addition, the results of this study showed positive effects of computer-based scaffolding on students' ability to generate evidence-based claims. This is in line with several studies that demonstrated the effectiveness of computer-based scaffolding on enhancing argumentation skills in ill-structured tasks across a broad range of students: middle level (Belland, 2008) and college level (Lin et al., 2012; Oh & Jonassen, 2007). The results of this study extend understanding about the effects of scaffolding on information literacy and argumentation skills in the context of problem-based learning. Furthermore, computer-based scaffolding to enhance these two skills functioned differently among students according to students' learning status and needs. That is, students could differently experience the effectiveness of scaffolding although the identical scaffolds were provided to every student. Students' different experience of computer-based scaffolds in this study supports the idea that different students can use scaffolding in different ways on the basis of differing goals and prior experiences (Belland & Drake, 2013). Consequently, this study demonstrated the current trends of computer-based scaffolding not only in favor of improving the content knowledge but also enhancing higher-order thinking skills and problem-solving skills in PBL.

There were a few exceptions. Some students regarded the hints, prompts, and feedback from VFT as a hindrance of their learning. In addition, they thought that the complicated structures provided by the *Connection Log* made their learning more difficult. These students also mentioned that they were not interested in learning anything, especially science subjects. This is a possible explanation of why computer-based scaffolding did not have any effect on students who did not want to use it (Simons & Klein, 2007).

Students' Different Experience in Problem-solving Process

This study also investigated how Information literacy and argumentation skills can be important factors required for the successful completion of each stage in PBL (ChanLin, 2008; Diekema et al., 2011; Kuhn, 1991; Means & Voss, 1996; Macklin, 2001; Toulmin, 1958). The most interesting finding from this study was that information literacy and argumentation skills affected students' problem-solving process in PBL in different ways (Barrows & Myers, 1993). In PBL, students need divergent thinking skills to creatively devise multiple solutions based on the qualified evidence, and then they could determine the most reasonable and appropriate solution among the devised several solutions of the given problem by convergent thinking (Birch, 1986). Advanced information literacy was helpful to gather the validated information and data from the credible resources as much as possible. However, this could not guarantee students' ability to make creative and evidence-based arguments. The possible explanation was that they had a lack of deep understanding about their information and the ability to organize given information (Belland, Glazewski, & Richardson, 2011). That is, they only showed advanced divergent thinking, not convergent thinking. This finding contradicts the results of previous studies, which reported successful outcomes of students by only advanced information literacy in PBL (Eskola, 2005; Fallon & Breen, 2005; Macklin, 2001). On the contrary, advanced argumentation skills were demonstrated as critical to the generation of well-organized solutions with sufficient and unified evidence. Nevertheless, there was few clear evidence about how students with the advanced argumentation skills put any efforts to find and justify information by themselves. In other words, they did not consider the importance of information to make their claims stronger and more reasonable (Azer, 2001).

In PBL in the context of K-12 education, information literacy skills were often seen as a pre-requisite for improving argumentation skills, not as an essential skill for engaging in PBL (Ge & Land, 2004). This led to a lack of studies on the importance of information literacy in PBL, resulting in the underestimation of the influence of information literacy on PBL. This study has the potential to clearly distinguish the roles of information literacy and argumentation skills on PBL, which might enlighten teachers and instructional designer about how information literacy and argumentations skills should be considered for successful PBL learning.

Limitations and Suggestions for Future Research

The participants were enrolled in credit recovery courses in summer in a small city, and it may be difficult to expand the results from this study into different student populations. Future research should be conducted to examine the effect of *VFT* and *CL* on learning in PBL in diverse educational settings (e.g., different grade levels and different ability levels).

Based on the interview with those students, I concluded that they closed the pop-up windows because they did not think that scaffolding was very helpful to address their current learning issues and needs. However, it might be possible for them to close the pop-up windows because they just want to get rid of hindrances on screen without any consideration of the contents from the pop-up windows. In future research, to reduce this confusion, various forms of scaffolding (e.g. on-screen message, pedagogical agent, and voice-typed supports) should be utilized.

The VFT had some issues in terms of air quality data. The first issue is the inclusion of a limited number of cities. For example, real-time data from AirNow (http://airnow.gov) was gathered by the reports from 400 USA cities, not from all cities. Therefore, the system could not provide air quality data for all cities students requested. If one asked the air quality of a certain city, which did not have any air quality data, the systems showed the air quality data in the closest city. Another issue is that some technical problems occurred because the real-time air quality data needed to be embedded into the existing virtual streets program provided by Google Street View. There were sometimes error messages due to the compatibility problems. Therefore, in the future, more stable and innovative software for measuring air quality is required. Google has recently started integrating air pollution levels in Google Street View. If the development of this function is completed, students can gather real-time air quality data more reliably and with much more accuracy in even more isolated areas.

The students in this study were not randomly selected and assigned. This led to high risk of bias in terms of 'random sequence generation' (Higgins & Green, 2008). This makes the generalization of results and discussion in this study difficult. Future research to follow adequate generation of a randomized sequence should be conducted. In addition, in qualitative research, one should consider the transferability of the results (Malterud, 2001). Generalization refers to the extension of findings and conclusions from the sample to the population level, but transferability means the extent to which results of studies can be applicable in similar or different learning contexts (Thomas & Magilvy, 2011). In qualitative research, transferability is important to build the external validity of findings (Jones & Lyons, 2004). This study investigated the effectiveness of computer-based scaffolding under the context of problem-based learning for solving a science phenomenon (i.e., air quality) on improving high school students' information literacy and argumentation skills. In other words, the findings and discussion from this study can be selectively applied as the evidence of the effectiveness of computer-based scaffolding to other learning contexts (e.g., different learning topics in science education, improvement of higher-order thinking skills, other problem-centered instructional models). However, this study has the limits to transfer the finding to the following fields of study- a) students' cognitive learning outcomes, b) different levels of population, c) other disciplines, and d) the traditional teacher-led instruction.

In addition, reliability analysis of TRAILS was not conducted due to small sample size. One alternative method, which can be utilized when one cannot run the classic reliability analyses (e.g., Cronbach's alpha) due to small sample size, is to utilize the Item

Response Theory (IRT) (Cappelleri, Lundy, & Hays, 2014). The results of the classic reliability analysis can be different in the different research and population. However, IRT assuming one parameter can generate the stable coefficient values of items regardless the samples (Magno, 2009). Fortunately, in one study, which estimated the item reliability of TRAILS from 60 high school students using the Rasch model as one of the IRT models, the reliability was at the acceptable level ($\alpha = 0.82$) (Salem, 2014).

Conclusion

To promote students' authentic inquiry in science education, problem-based learning (PBL) has been used as an instructional approach (Belland et al., 2011; Savery, 2015). Information literacy and argumentation skills are central to success in PBL (Diekema et al., 2011; Oh & Jonassen, 2007). In this study, the effects of computer-based scaffolding on improving students' two skills in PBL were demonstrated. Furthermore, the study demonstrated students' various experiences in the problem-solving process as a function of their different levels of information literacy and argumentation skills. The results may have important implications in that information literacy and argumentation skills may be the pivotal factors in PBL for science learning, which should not be overlooked.

CHAPTER V

ENHANCING STUDENTS' HIGHER ORDER THINKING SKILLS THROUGH COMPUTER-BASED SCAFFOLDING IN PROBLEM-BASED LEARNING: MULTIPLE PAPER DISSERTATION

Abstract

This multiple paper dissertation addressed several issues in Problem-based learning (PBL) through conceptual analysis, meta-analysis, and empirical research. PBL is characterized by ill-structured tasks, self-directed learning process, and a combination of individual and cooperative learning activities. Students who lack content knowledge and problem-solving skills may struggle to address associated tasks that are beyond their current ability levels in PBL. This dissertation responds to debates on a) scaffolding characteristics and their effects on students' perception of optimal challenge in PBL, b) the possibility of virtual learning environments for PBL, and c) the importance of information literacy for successful PBL learning. Specifically, this dissertation demonstrated the effectiveness of scaffolding customization (i.e., fading, adding, and fading/adding) to enhance students' self-directed learning in PBL. Moreover, the effectiveness of scaffolding was greatest when scaffolding customization occurs by students' decision rather than by fixed-time interval and their performance. This suggests that it might be important for students to take responsibility for their learning in PBL and individualized and just-in-time scaffolding can be one of the solutions to address K-12 students' difficulties in improving problem-solving skills and adjusting to PBL.

The Purpose of Multiple Paper Dissertation

K-12 students who are used to teacher-led instruction often struggle to adjust to PBL (Hung, 2011; Jonassen, 2000). To address this issue, scaffolding, defined as just-in-time supports to help students accomplish tasks that are beyond their current abilities (Wood, Bruner, & Ross, 1976), has been designed and implemented in PBL. However, current scaffolding systems have the following three main challenges. First, existing scaffolds do not consider students' diverse needs during PBL and students often receive undifferentiated support in spite of different background knowledge, learning skills, and motivation (Greene & Land, 2000; Mercer & Fisher, 1992). This makes it difficult for students to overcome learning challenges encountered during PBL.

Second, although scaffolding to support students' diverse needs in PBL is designed based on the literature, it might be difficult to predict the actual effects of suggested scaffolding in the learning environment due to a lack of systematic review about the characteristics of scaffolding in PBL (Belland, 2016; Belland, Walker, Kim, & Lefler, in press). To address this issue, meta-analysis to integrate the results of studies related to scaffolding is required. Some such work has been done (Belland, Walker, Olsen, & Leary, 2015; Zheng, 2016), but it has not been targeted specifically at scaffolding used in PBL.

Third, information literacy and argumentation skills are regarded as essential skills in PBL in that those skills are necessary to find, evaluate, and utilize information as well as to generate reasonable claims supported by this information as evidence. Nevertheless, there are few studies that consider the role of scaffolding in improving K-

12 students' information literacy and argumentation in PBL in parallel. Moreover, there is no evidence about the influence of information literacy and argumentation skills supported by scaffolds on improving students' problem-solving skills in PBL.

This multiple-paper dissertation addressed the above-mentioned three issues in PBL through conceptual, meta-analysis, and empirical papers (See Figure 1).

Discussion

There have been many meaningful attempts at designing scaffolding to enhance students' learning performance and understanding the content knowledge. However, recently the role of scaffolding has expanded from presenting simple feedback on students' performance to providing more dynamic and individualized supports based on the ongoing diagnosis of students' current learning status (Azevedo & Hadwin, 2005: Belland, 2014).

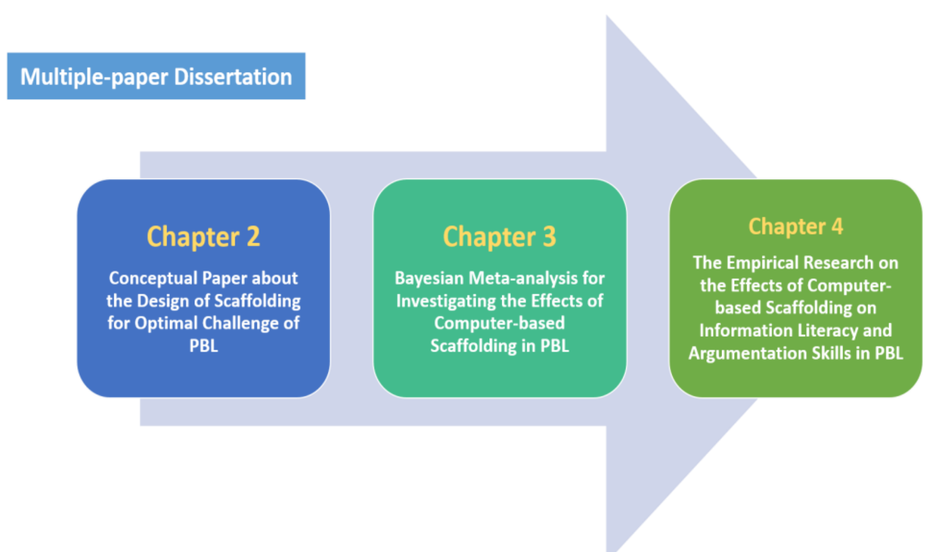


Figure 1. The flow of the multiple-paper dissertation.

Especially in PBL, which requires students' self-directed learning skills, tailored scaffolding is a crucial factor in student success (Greening, 1998; Savery, 2015; Simons & Klein, 2007). Nevertheless, many scaffolds do not provide both individualized and just-in-time support although some advanced scaffolding systems (e.g., intelligent tutoring systems) endeavor to do so (Tammets, Laanpere, Ley, & Pata, 2013). This multiple-paper dissertation suggested an optimized scaffolding design for PBL learning, investigated the effectiveness of diverse scaffolding characteristics through Bayesian meta-analysis, and actually applied an enacted system informed by the conceptual paper and the Bayesian meta-analysis in PBL for high-school science education.

Multiple Types of Scaffolding

The just-in-time provision of multiple types of scaffolding (i.e., conceptual, metacognitive, strategic, and motivational scaffolding) according to each student' needs and difficulty can help students understand a given problem statement, create reasonable solutions based on gathered information and data, and enhance their confidence in their learning (Chen, Kao, & Sheu, 2003). This means that PBL requires diverse abilities from students for problem-solving (Hmelo-Silver & Barrows, 2006), and scaffolding should satisfy a lack of students' abilities through several types of supports (Puntambekar & Kolodner, 2005).

Many scholars have considered utilization of scaffolding to address students' diverse needs and difficulties encountered in PBL (Puntambekar & Kolodner, 2005; Tabak, 2002). However, roles of existing scaffolds have been restricted to focus on a certain area of difficulty such as domain knowledge, learning strategies, and collaborative learning without any consideration for the many types of learning difficulties brought on by deficiencies in knowledge or skills (Belland et al., in press). In addition, the original purpose of scaffolding is to provide individualized supports and tutoring based on the dynamic diagnosis of students' current learning status (Wood et al., 1976), but current scaffolding is still far from being enough to satisfy the original definition of scaffolding (Belland, 2016).

Learner-centered Scaffolding System (LSS) suggested in this paper enhances students' sense of responsibility for their learning and confidence that they will accomplish their tasks by providing multiple types of scaffolding in accordance with students' different needs and difficulties in PBL. Distributed scaffolding suggested by Puntambekar & Kolodner (2005) is consistent with the intended purpose of multiple types of scaffolding in that various types of scaffolding are provided according to each student's current needs, understanding, interest, and motivation. However, the limitation of Puntambekar & Kolodner (2005)'s study is that they did not mention anything about the specific design principles of the distributed scaffolds, resulting in difficulty for other scholars to reproduce the multiple types of scaffolds. However, this dissertation specifically explained the goal and examples of each scaffolding type, and the suitable time and situation to utilize these scaffolds. In addition, these multiple types of scaffolding, which were adopted in the empirical research, showed how these scaffolds could improve students' problem-solving skills and higher-order skills, leading to better performance in PBL.

However, not all types of scaffolding were effective in PBL. Based on the results of meta-analysis, conceptual scaffolding showed the lowest effect size (g = 0.126) among the types of scaffolding even though a majority of studies utilized conceptual scaffolding (*N*= 31, 66%). The low effect size of conceptual scaffolding may be explained by the fact that the tasks in problem-based learning do not require students just to structure and problematize the given tasks by considering things to be needed in the process of problem-solving, but also require students' ability to apply the knowledge in the real word (Barrows, 1994). That is, students' metacognition (g = 0.384) and learning strategy (g = 0.345) supported by computer-based scaffolding can play an important role in students' successful learning in PBL. However, this result cannot clearly explain the low effect of conceptual scaffolding. Therefore, more specific investigation into the cause of low effects of conceptual scaffolding in PBL is required through the qualitative meta-synthesis of the empirical studies.

Unfortunately, studies that apply multiple types of scaffolding according to students' ability, understanding, and motivation in their research such as Hannafin, Land, and Oliver (1999) originally suggested have been rare. Certainly, there were some cases, which used multiple scaffolds as diverse interventions independently, but these were just for determining the effectiveness of each scaffolding type (Fund, 2007; Gijlers, 2005; Kinnebrew, Segedy, & Biswas, 2014). In addition, advanced scaffolding systems such as intelligent tutoring system (ITS) have tried to provide customized scaffolding based on students' current learning process, but these systems still do not have the ability to make any discrimination between students' shallow learning and deep learning. Therefore, it might be difficult for them to identify whether a student's request of scaffolding is based on the real necessity or not.

Providing multiple types of scaffolding in the true sense of the word is not easy due to the difficulty in continuously diagnosing students' current learning status and technical issues. However, new attempts using artificial intelligence for computer-based scaffolding are under way. Currently, many scholars are trying to incorporate machine learning techniques in computer-based scaffolding or intelligent tutoring systems (Aleven, Roll, McLaren, & Koedinger, 2016; Gross, Mokbel, Hammer, & Pinkwart, 2015; Montalvo, Baker, Sao Pedro, Nakama, & Gobert, 2010). Machine learning can diagnose students' current needs and learning ability through classifier building, Bayesian prediction models, and data mining with high accuracy. If machine learning as a technique for scaffolding provision can be combined with LSS in the design of scaffolding, students get individualized and customized scaffolding according to their needs.

Computer-based Scaffolding, Teacher-based Scaffolding, and Peer Scaffolding

This dissertation confirms once again that computer-based scaffolding alone is still far from a perfect instructional means to support students' advanced knowledge and higher-order skills. For the empirical study, the design of scaffolding system included several types and customization of scaffolding and CSCL to overcome the limitations of existing scaffolding systems. However, some participants in chapter IV still preferred teacher-based supports to computer-provided help due to unfamiliarity with learning by computers and a doubt on the credibility of information by computers (McNeil &

Krajcik, 2009; Schofield, Eurich-Fulcer, & Britt, 1994). This can be a reasonable rationale for the combination of teacher and computer-based scaffolding as LSS suggested (Puntamberkar & Kolodner, 2005; Saye & Brush, 2002). The most effective and efficient delivery of scaffolding comes from the powerful integration of teacher scaffolding, just-in-time supports and elaboration, with the immediate supports of computer-based scaffolding (Reiser, 2004; Tabak, 2002). As an example, at the beginning of learning, teachers play a role in providing every student general supports for structuring and guiding the PBL units. Computer-based scaffolding, then, can present supports to each student in a class based on their learning process and the steps they are performing. Then, if there is a student for which the computer-based scaffolding is not sufficient to address their current learning concern, the teachers can provide customized and more sophisticated supports. Therefore, the burden of being a scaffolding provider is greatly reduced for these teachers as they need only handle students that require more advanced supports. In chapter III, there were some cases in which computer-based scaffolding provides the generic scaffolds and teacher added more supports if students needed the additional help (Hmelo-Silver & Day, 1999; Kajamies, Vauras, & Kinnunen, 2010). The effect sizes of these cases (g = 0.83, g = 0.74) were much higher than the average effect size (g = 0.39) when only computer-based scaffolding was provided.

According to the original definition, scaffolding can be also provided by more proficient persons (Woods et al., 1976). This type of person may be peers in the same classroom. More capable students can access, evaluate, and critique lower-achieving students' learning (Kolodner et al, 2003). More capable students can assist low-achieving students by the forms of hints, questioning prompts, expert modeling and feedback with a guideline of provision of peer scaffolding (Belland, 2014). In addition, students can perform the tasks while watching the execution process of other students and expand their thinking related to problem-solving (Belland, 2014). In PBL group work is one of the essential procedures to complement individual students' lack of skills by obtaining more reasonable solutions and further information from peers. In this regard, many studies have been conducted to demonstrate the effectiveness of peer scaffolding (Kolodner et al., 2003; Oh & Jonassen, 2007; Pifarre & Cobos, 2010). However, contrary to the above-mentioned rationale for using peer scaffolding, there is another opinion that collaborative learning among students with similar ability improves the intrinsic motivation by raising their interests and it leads to students' better performance (Csikszentmihalyi, 1996). Groups often include one or two students who show a passive attitude to learning due to a lack of motivation, learning goal, and ability (Kaufman, Felder, & Fuller, 1999). This type of student negatively affects group members' works and deliberately tends to ignore advice from more advanced students. Moreover, more capable students may experience a decrease in their immersion in learning due to the delay caused by the other students' slow learning pace. This can cause unequal participation and a lack of discussion in a group, which consists of students with different abilities and learning paces. Therefore, this dissertation suggested scaffolding from peers with smilar abilities and learning paces (Slavin, Madden, & Leavey, 1984). If a student requests help from peers, computer systems can connect students that have similar levels of individual learning and current learning pace, instead of students who have more advanced knowledge and skills. If peer scaffolding between similar-ability students is not supportive and helpful to each other due to a lack of evaluation skills and content knowledge, computer systems can recognize this issue, and then regroup the peers with a slightly advanced student. In some ways, the suggested peer scaffolding can be against the definition of original scaffolding by Woods et al. (1976), which refers to the supports by more proficient persons. However, LSS in this dissertation is the combination of several scaffolding modalities. Ideally, students get main supports about content-knowledge and learning strategies from computer systems and teachers. Additionally, they can improve their interests and confidence in their learning from peers in collaborative learning.

Scaffolding Customization

By effectively controlling the timing and degree of scaffolding, students reach the final learning goal by their own learning strategies and processes (Collins, Brown, & Newman, 1989). The adjustment of support has been recognized as an effective component of scaffolding from the original definition of scaffolding (Wood, Bruner, & Ross, 1976) and some scholars emphasized the role of fading (Collins et al., 1989; Dillenbourg, 2002; Puntambekar & Hubscher, 2005) and adding (Koedinger & Aleven, 2007; Koedinger & Corbett, 2006) as adjustment mechanisms of scaffolding. In PBL, which requires students' self-directed learning, fading and adding of supports can be essential factor to improve students' responsibility for learning by controlling learning pace by themselves (Hoffman & Ritchie, 1997). This can lead to students' perception of optimal challenge in PBL through enhanced autonomy and confidence in accomplishing the tasks. Nevertheless, contrary to the claims from many scholars who emphasized the importance of fading (Collins et al., 1989; Dillenbourg, 2002; Puntambekar & Hubscher, 2005) and adding supports (Koedinger & Aleven, 2007; Koedinger & Corbett, 2006), some meta-analysis showed that the effects of fading and adding do not differ from that of no fading or adding (Belland et al., in press). Furthermore, few researchers have utilized these fading and adding supports in their studies. Only 15 studies (32%) out of 47 studies included in Bayesian meta-analysis incorporated scaffolding customization regardless of the recognition of the importance of scaffolding customization. This corresponds with the finding of other meta-analyses (Belland et al., in press, Lin et al, 2012). One possible reason is that it is not clear how scaffolding design about customization should be done and how this scaffolding customization can support students' learning. One important finding from this dissertation was to demonstrate the effectiveness of fading and adding supports in PBL. The effect sizes of fading, adding, and fading/adding supports were appreciably higher than no scaffolding customization, and this result might be worthwhile in that it lends empirical support to Wood et al (1976)'s initial claims on the importance of scaffolding customization for the first time.

Another interesting finding is the effectiveness of scaffolding customization by students' self-selected decision in PBL. Typically, scaffolding customization can be conducted by fixed-time interval, diagnosis on students' performance, and self-selection (Belland et al., in press). However, few studies explained the characteristics and benefits of each scaffolding customization methodology. This dissertation suggested that self-selected fading and adding can be a good method to improve students' self-confidence for the successful accomplishment of tasks as effectively controlling the timing and degree of fading by themselves in PBL. This claim is supported by findings from Bayesian meta-analysis on the effectiveness of computer-based scaffolding in PBL in which self-selected scaffolding customization was the best choice to directly improve students' learning performance rather than the change of scaffolding by performance-adapted and fixed-time interval. One limitation of scaffolding customization by self-selection is students' insufficient ability to diagnose their learning process and to determine whether scaffolding is still needed or not (Aleven & Koedinger, 2002; Hadwin & Winne, 2001). However, current advanced computer-technology has enough capacity to recognize students' current learning progress based on their learning stage, performance, and time. Therefore, the computer system can play a supportive role in helping students' judgment about the decision of scaffolding customization.

Optimal Challenge in PBL

The goal of PBL is a) to enhance students' higher order thinking skills, b) to build their own learning strategies, c) to improve the intrinsic motivation to learning, and d) to help them to be the cultivated life-long learners (Barrows, 1986; Hmelo-Silver, 2004; Loyens, Magda, & Rikers, 2008). For achieving these goals, students' self-directed learning and tasks reflecting the realistic situations are essential (Loyens et al., 2008). However, students can experience several types of difficulties during PBL because of students' different levels of background knowledge, learning skills, and motivation (Dolmans & Gijbels, 2013). This leads to students' difficulty to perceive the given tasks in PBL as optimally challengeable. This issue cannot be solved by adjustment of task-difficulty levels alone, as it is in traditional teacher-led instruction due to the complicated learning process of PBL. This dissertation explained the reason why scaffolding should be considered to enhance students' perception of optimal challenge in PBL by suggesting multiple types, delivering methods, scaffolding customizations, and CSCL. If students receive individualized supports based on their learning status and can control the amounts and frequency of supports by themselves, their autonomy, competence, and relatedness will be enhanced and this, in turn, can enhance students' perception of optimal challenge (Dahlgren & Dahlgren, 2002; Hmelo-Silver & Barrows, 2006). As a consequence, student confidence to take on the ill-structured nature of PBL will increase and student problem-solving abilities will grow (Guglielmino, 2008; Lefever-Davis & Pearman, 2015).

Reconsideration of Information Literacy in PBL

In PBL students should be able to exactly recognize what they know and what they should know in terms of the given problems, and then if they need more information to address the problems, they have to effectively find, evaluate, and utilize information by themselves (Barrows, 1986). In other words, information literacy, which defines a student' ability to find, evaluate, and utilize information, should be a prerequisite for engaging in PBL (Diekema, Holliday, & Leary, 2011; Macklin, 2001). It is daunting for students to generate reasonable solutions and evidence-based arguments without enough information literacy in PBL (Ward, 2006). Nevertheless, many studies related to PBL have overlooked the importance of information literacy (Diekema et al., 2011). Even in some studies (Huang, 2011; Kil, 2014), which were conducted in the context of PBL, teachers played the role of information provider to help students find solutions faster and simpler without any learning activities related to students' information literacy. However, in PBL, teachers should be facilitators who support students' learning process (Barrows, 1996). In Bayesian meta-analysis, around 8% of the original corpus of articles were excluded due to the teachers' role as an information provider, not as a facilitator. This can be an evidence as to how much information literacy has been underestimated in PBL. Alternatively, in the educational field, the primary goal and process of PBL have not yet been agreed upon by scholars (Koh, Khoo, Wong, & Koh, 2008).

The research result in this dissertation clearly showed why information literacy should be recognized as one of the essential abilities for successful PBL. Without advanced information literacy, students' claims for the final solutions were just an expression of personal opinion, not evidence-based arguments (Moselen & Wang, 2014; Walsh, 2014). Consequently, it may be time to reconsider the role of information literacy in PBL and to revise the methods to improve students' information literacy in PBL. Computer-based scaffolding that considers students' different interests and abilities can be one of the solutions that addresses this issue as this dissertation has demonstrated.

The Possibility of Virtual World as Effective Learning Environments

This study demonstrated the possibility of a virtual world as an effective learning environment to improve students' understanding of a problematic situation and enhance engagement in the learning activities in PBL (Beadle & Santy, 2008; Nelson, Sadler, & Surtees, 2005). Students' direct experience in gathering data in a learning context can be the most effective way to contextualize a problematic situation (McDermott, Shaffer, &

Constantinou, 2000). However, it is not always feasible to give students direct experience. Recently, virtual learning environments, defined as out-of-school activities and computer-generated environments, have emerged to allow students to virtually visit a certain place for the purpose of learning without ever leaving the classrooms.

For example, if students want to learn about air quality, they could go on a virtual field trip to collect and analyze air quality samples across U.S. cities. As the role of direct experience in authentic environments has long been touted as central to strong learning outcomes (Dewey, 1966), incorporating virtual field trips in science education in this study can lead to students' improved recall of scientific knowledge (Miglietta, Belmonte, & Boero, 2008), higher achievement (Falk & Needham, 2011), and more positive attitudes towards science. This result corresponds with other studies, which utilize virtual worlds in the context of problem-based learning (Omale, Hung, Luetkehans, & Cooke-Plagwitz, 2009; De Freitas & Neumann, 2009).

The thing that differentiates *virtual field trip* used in this dissertation from the existing studies using the virtual learning environment is the addition of *Augmented Reality*. Currently, rapid advances in technology make the virtual world as a learning environment more realistic and tangible (Lee, Jang, Moon, Cho, & Lee, 2016). *Augmented Reality* could potentially be one of these new technologies. *Augmented Reality* shows the real world on the screen of handheld devices or computers in real time overlaid with information and data related to the given tasks (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012). This *Augmented Reality*-based content provides realistic information to learners and has attracted attention as a new educational resource that implements direct manipulation activities (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008). Students investigating a natural phenomenon could not only bring artifacts into their classroom experience but could also transport their environment into view; a much more realistic and valuable experience than just learning from a two-dimensional resource from textbooks or the internet.

Bayesian Meta-analysis

Numerous studies with the same or similar research topic have been conducted, but it is difficult to simply compare the effects of a certain treatment from individual studies due to the different participants, experimental conditions, and treatment interventions across the studies (Hedges & Olkin, 2014; Mark, Lipsery, & Wilson, 2001). One method to generalize the effect of a certain treatment is meta-analysis (Hunter, Schmidt, & Jackson, 1982). Meta-analysis is an effective methodology to synthesize the results from multiple individual studies by a standardized value called the effect size (Hedges & Olkin, 2014). However, many scholars have criticized the inaccurate results of meta-analysis that result from procedural issues, inadequate data analysis and small effects (Greco, Zangrillo, Biondi-Zoccai, & Landoni, 2013). There is one study that reports that 86% of meta-analyses included publication bias, which can cause biased results (Kicinski, 2013). To address this issue, in the medical and business fields where meta-analysis is widely used, many scholars are trying to apply new statistical techniques (e.g., Bayesian approach).

This dissertation pointed out the problematic issues of traditional meta-analysis, and adopted Bayesian inference as new approach to meta-analysis. Currently, Bayesian models have been actively utilized in various fields (i.e., artificial intelligence, marketing, data analytics, medical, and engineering) due to its accurate prediction of a phenomena, activities, and data. Meta-analysis using Bayesian approach in this dissertation also demonstrated how small study effects could be overcome, resulting in production of more reliable and accurate effect sizes of computer-based scaffolding (Pitchforth & Mengersen, 2012). However, there are still difficulties for educational scholars to use Bayesian approach as the method of data analysis for the following reasons. First, Bayesian analysis requires advanced statistical knowledge and technique (Berger, 2013). Contrary to frequentist statistics, which can be analyzed using GUI-based software, all software for Bayesian analysis is operated by text-based interface. This makes the utilization of Bayesian method harder. Second, there is an issue of interpretation. The interpretation of the results from Bayesian approach is totally different from one by the frequentist approach caused by a different inferential approach (i.e., Credible Interval VS Confidence interval) (Press, 2012). Nevertheless, many scholars who are already familiar with the frequentist approach tend to interpret the results of Bayesian analysis in the same way as frequentist-analysis results. To address the above-mentioned issues, this dissertation provides important guidelines for analysis process and interpretation of Bayesian analysis. In addition, this has the potential for Bayesian approach to overcome the limitations of traditional meta-analysis using the frequentist approach.

Limitation and Future Research

The purpose of this multiple-paper dissertation is to suggest a scaffolding design that can improve students' perception of optimal challenge and learning performance in

PBL. In addition, Bayesian meta-analysis and the empirical research demonstrated the effectiveness of the suggested scaffolding design in PBL. Bayesian meta-analysis (BMA) can allow researchers to generate more accurate effect sizes by probabilistic inferences although a number of studies within a certain moderator is so small (Schmid & Mengersen, 2013). However, the probability cannot exactly tell us what is actually done in the real world, and it is just a prediction. The results of BMA were reasonable with a high level of probability, but an exception can occur. Thus, one should not have blind faith in the BMA results. In addition, if the empirical research related to variables do not exist, there are no methods to estimate the effect sizes in even BMA. For this reason, many components of scaffolding design, which was suggested by chapter II, could not be involved in this BMA. To address this issue, more studies using the suggested scaffolds are required, and future research by traditional meta-analysis with a sufficient number of students is needed to confirm the result of BNMA. Another limitation of this dissertation is that it might be difficult to generalize the results of the empirical research. The participants were 11^{th} -12^{th}-grade students who were enrolled in a credit recovery, environmental science class in a public school in the Intermountain West, and it might be difficult to expand the results from this study into different student populations with various cultures, abilities, races, and regions. Future research should be conducted to examine the effect of *Virtual Field Trip* and *Connection Log* on learning in PBL in diverse educational settings (e.g., other cities in U.S., other countries, and students with different grades (e.g., primary, middle, and college level) and different ability level (e.g., low, middle, and high-achieving level), and it is required to identify whether the results from this study are consistent with those from the future studies. In addition, some of the scaffolding features suggested in Chapter II were beyond the range of small, individual dissertation due to the technological and cost limits. This was a limitation to demonstrate the effects of all suggested scaffoldings through direct application in the empirical research. Future empirical research with more elaborate scaffolding design and a broad range of participants should be conducted to demonstrate the effectiveness of the suggested scaffolding system.

Conclusion

Problem-based learning has the potential to improve students' scientific inquiry and self-directed learning skills by actively engaging in ill-structured/authentic problem-solving process (Savery, 2015). However, K-12 students, who are unfamiliar with the learner-centered instructional model, often struggle during PBL due to the complicated learning process, a lack of self-directed learning and cooperative learning skills, and the insufficient ability of teachers as a facilitator (Wijnia, Loyens, Derous, & Schmidt, 2015). This multiple paper dissertation suggested Learner-centered Scaffolding System to address students' difficulties and needs occurred in PBL. This system provides multiple types, sources, and customization of scaffolding, and students can experience optimal challenge of the given PBL problems by overcoming their difficulties occurred in PBL process. This is because students can improve their intrinsic motivation related to autonomy, competence, and relatedness supported by scaffolding. I also checked the effectiveness of suggested scaffolds through meta-analysis. The results from BMA indicated that computer-based scaffolding in PBL enhanced students' advanced problem-solving skills and thinking strategies as identifying the components of information and ideas (Arts, Gijselaers, & Segers, 2002; Greening, 1998; Vasiliou, Ioannou, Arh, Zaphiris, & Klobučar, 2013). Moreover, when scaffolding was customized by the combination of fading and adding as well as by fading (Collins et al., 1989) and adding supports (Koedinger & Aleven, 2007) individually based on students' learning status and needs, strong learning outcomes resulted.

I also found a significant impact of computer-based scaffolding, which was designed based on the suggested scaffolding design and the results of BMA, on information literacy and argumentation skills through the empirical research. This result in this study indicated that individualized and just-in-time scaffolding can be one of the solutions to address K-12 students' difficulties in improving problem-solving skills and adjusting to PBL (Mayer, Moeller, Kaliwata, Zweber, Stone, & Frank, 2012; Smith & Cook, 2012).

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CHAPTER I

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CHAPTER II

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CHAPTER IV

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CHAPTER V

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APPENDICES

Appendix A

Computer-based Scaffolding Examples in *RIM*

Scaffolding Types	Examples	Scaffolding Forms
Strategic scaffolding	"Air quality can be determined by the several levels of pollutants, and you need to check these pollutants, which have a huge impact on a city you selected. Please visit this web-site"	Prompts
Conceptual Scaffolding	"Car exhaust fumes (any reasons) are known as the biggest reason to increase CO (any pollutants). Based on your measurement of CO in Logan (any cities), can you tell whether high CO in Logan is caused by vehicles? Is there another factor behind the high levels of CO? Please show your evidence"	Questions
Strategic scaffolding	"As you understand, the components of air quality are diverse. On the screen, you can see two types of tools to measure air quality. Unfortunately, there is no tool to estimate all kinds of components. One is for chemical components (CO, NO…), and another is for physical components (PM2.5). For accurate measure, you should choose the proper tool. First of all, you need to know whether a certain component you try to measure is chemical or physical.	Hints
Metacognitive Scaffolding	"In 2015, the pollution, especially Ozone, of air quality in Logan rapidly got better. What is the possible reasons on this happening?	Questions
Motivational scaffolding	"You are a little bit behind your team members. Two students in your groups have already finished their measurement. However, It does not matter how long it takes as long as you measure air quality accurately"	prompts
Conceptual scaffolding	"API is calculated by the combination of each pollutant. This is a formula, in which experts calculate API based on the data from the several pollutants. Using this formula, you can also calculate API based on the data of each component you measured.	Expert modeling
Strategic scaffolding	"To operate AVS-0323, Please follow this process. 1) turn on Power 2) push the 'reset' button 3)select the pollutant 4) push the 'start' button 5) wait 10 seconds 6) please push the 'save' button 7) Do not push any button while measuring. Be aware of the possibility of losing your data	Hints
Conceptual scaffolding	"You finished your measurement. Next step is to figure out the pollutants standard to determine air quality. Check the following url"	Prompts
Metacognitive scaffolding	"Your level of several pollutants is different compared to your team members. Please reflect on your	prompts

	procedure of measurement or think about the reason of difference”	
Metacognitive scaffolding	“You chose this site- www.ift.thought. Are you certain that information from this site is credible? If not, please re-visit the helios room to learn ‘information-searching’”	Prompts
MetacognItive scaffolding	“According to API history, there is a huge wave in the level of air pollutants in a city you chose. Can you find any information about this and explain the reason of a huge wave?”	Questioning
Strategic scaffolding	“You successfully gathered the data and information to solve the given problems about air quality. If you still need more data and information, you can re-visit VFT. If not, please go to the Connection Log. In Connection Log, you can create the claims for problem-solving based on your evidence. The list of information and the results of data will be provided to you as the form of paper.”	prompts

Appendix B

TRAILS: Tool for Real-time Assessment of Information Literacy Skills

Pre-test

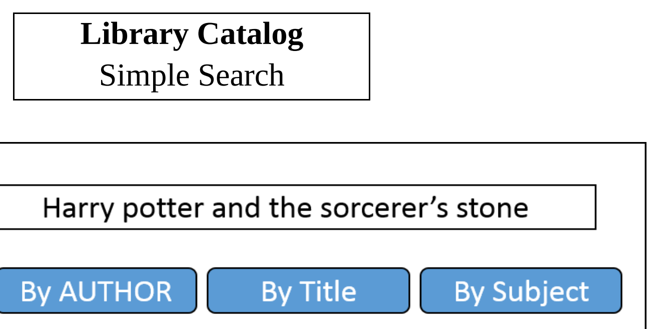
1. In English class your group is creating a pamphlet about child abuse, and this pamphlet will be distributed in your school and community. Select the correct order for these research steps:

A. Evaluate and record information from a variety of resources.
B. Organize information and create a rough draft version of your pamphlet.
C. Locate appropriate resources.
D. Create a final version of the pamphlet.
E. Review the success of your research and final pamphlet.
F. Determine the focused topic of your research.

CHOOSE ONE ANSWER.

O C F A B E D
O F B A C E D
O C F B A D E
O F C A B D E
O F C B A D E

2. The following picture is from an online library catalog. If you were searching for the book *Harry Potter and the Sorcerer's Stone* which search type would you choose? *CHOOSE ONE ANSWER.*



O All fields
O Author
O Title
O Subject

3. You're writing a paper on Indira Gandhi, and your teacher told you that Gandhi is mentioned in a book that you have. What part of the book will direct you to the right pages for the passage(s) on Indira Gandhi? *CHOOSE ONE ANSWER.*

O bibliography
O footnotes

O index
O preface
O title page

4. Using a symbol such as *, #, or $ in the middle or at the end of a search term (example: racis$) so that variations of the term (examples: racism and racist) will be retrieved in your search is known as: *CHOOSE ONE ANSWER.*
O Annotation
O Indexing
O Paraphrasing
O Truncation

5. If you wanted to search for a topic that has several parts, such as nutrition for pregnant women, which search operator would you use? *CHOOSE ONE ANSWER.*
O adj
O and
O near
O not
O or

6. Read the original topic and the revised topic. Is the revised topic broader or narrower than the original topic? *CHOOSE ONE ANSWER.*
Initial Topic: What steps must public high schools take to establish on-site daycare for children of teenage parents attending school?
Revised Topic: How can public high schools help teenage parents stay in school?
O Broader
O Narrow

7. Consider the topic below as possible for a three-page research paper. Indicate whether the statement would be a Good Topic for this paper, a Topic Too Broad for this paper, or a Topic Too Narrow for this paper.
Explain the impact of the Internet on education. *CHOOSE ONE ANSWER.*
O good topic
O Topic too broad
O Topic too narrow

8. In your science class you have been assigned “fire” as your topic in the natural disaster unit. Which of the following would be the best individuals to help you focus your topic? *CHOOSE ONE ANSWER.*
O City mayor, Your school or public librarian, Your science teacher

O Your school or public librarian, Your science teacher, Firefighter
O police officer, Firefighter, City mayor
O City mayor, your school or public librarian, Firefighter

9. All of the following concepts are related to nutrition. Which word represents the narrowest (most specific) topic? *CHOOSE ONE ANSWER.*

O Carbohydrates
O Vitamins
O Minerals
O Calcium
O Protein

10. When students are assigned a topic, it is often quite broad. Thus, it is a student's responsibility to focus the topic into a more manageable one.
Which of the following does not follow the pattern of a broad topic (on the far left) reduced to a narrower topic (on the far right)? *CHOOSE ONE ANSWER.*

O Ecosystem--desert--sand dune
O Oceanography--the causes of tsunamis--earthquakes
O Binge drinking--binge drinking at college--the effect of alcohol laws on binge drinking
O Child malnutrition--world hunger--contributors to childhood malnutrition

11. Which one of these resources would most likely have a current article on steroid use in professional baseball? *CHOOSE ONE ANSWER.*

O a school library catalog
O a science database such as Access ***Science***
O a newspaper database such as ***Newspaper Source***
O a biography database such as ***Gale Biography Resource Center***
O a biography database such as ***American National Biography***

12. What term describes information created during the time period in which the person of interest lived or the event took place? Examples include initial reports of scientific research, legal documents, speeches, correspondence, diaries, and interviews. *CHOOSE ONE ANSWER.*

O primary source
O secondary source
O tertiary source

13. You need to locate information on how people danced during the disco era for your

dance project. Where could you most likely find this information? *CHOOSE ONE ANSWER.*

O hospital library
O public library
O academic library
O government library

14. In your geography class each student has been assigned a foreign country. As part of your project you are to draw a map of your assigned country and include your country's geographic features (rivers, mountains, etc.) and its bordering countries. Which resources would be the best ones to use? *CHOOSE ONE ANSWER.*

O dictionary and newspaper
O atlas and encyclopedia
O thesaurus and atlas
O encyclopedia and almanac

15. "Being an expert on a particular subject..." is one definition for:
CHOOSE ONE ANSWER.

O coverage
O accuracy
O objectivity
O currency
O authority

16. You have to write a persuasive paper on the merits of the European Union. You are unfamiliar with this subject. Which source would be the best starting point for getting background information? *CHOOSE ONE ANSWER.*

O A book entitled, Competition Law and Industrial Policy in the EU (376 pages)
O A recent USA Today article entitled, "U.S. and European Union call truce on trade war -- for now " (453 words)
O Encyclopedia Britannica
O Journal of European Economic Development

17. When you evaluate a website's coverage, which of the following do you not examine? *CHOOSE ONE ANSWER.*

O The depth of the material
O If the website offers information that is not found in other websites or print sources
O Who created the website, including his/her background (credentials)

O If the links are relevant to the topic

18. You read on the Web that Mad Cow Disease may have been found in the United States. How might you best determine the truth of this statement? *CHOOSE ONE ANSWER.*

O Check the website www.fbifiles.com for information the government might not release to the public.
O Search for "Mad Cow Disease" on the U.S. Department of Agriculture website.
O Look up the topic on the website from the American Council on Beef .
O Discuss the news with friends who might have heard about Mad Cow Disease.

19. Being information literate means being able to identify when two or more sources agree and disagree. Read the two paragraphs below. Select the one statement on which both authors agree.

Author #1

Worldwide every day 14,000 people become infected with HIV. Of these 14,000 people, approximately 1,700 are children. In fact, more than half of the global HIV infections occur in young people ages 15-24. This high rate is partly due to young people not knowing how to protect themselves from HIV transmission. Globally, youth also feel the burden of HIV in another way. AIDS has orphaned approximately 15 million children.

Author #2

The Centers for Disease Control and Prevention estimates that 40,000 people in the United States become infected with HIV every year. HIV can be transmitted through bodily fluids such as blood and breast milk. Therefore, babies born to mothers with HIV can also become infected. Pregnant women can be tested for HIV and receive drug treatment to prevent their babies from contracting HIV.

CHOOSE ONE ANSWER.

O Babies can become infected with HIV through their mothers.
O Children are at risk of becoming infected with HIV.
O Over 50% of HIV infections occur in young people

20. You are completing your research paper on the devastation of the Amazon rainforest caused by logging. You locate a statistic from a recent newsletter created by the Lumberjacks of the Great Northwest.

Which of the following best reflects the credibility of this source? *CHOOSE ONE ANSWER.*

O This is a credible source because there is a clear author.
O This is a credible source because there are images and graphs.
O This is not a credible source because the author is likely to be biased.

O This is not a credible source because there are misspellings.

21. You are creating a video for your science class, and you want to include a sound clip from a popular song. How much of the song may you include without violating copyright? *CHOOSE ONE ANSWER.*

O up to 3% of the song length, but no more than 9 seconds
O up to 10% of the song length, but no more than 30 seconds
O up to 20% of the song length, but no more than 1 minute
O There is no time limit because the song is being used for a classroom assignment.

22. What is the best definition of intellectual freedom? *CHOOSE ONE ANSWER.*

O The prevention of cheating by students.

O The right of every individual to both seek and receive information from all points of view without restriction.

O The limiting of access to ideas and information that some people find objectionable or dangerous.

23. When your original creation (poem, video, song, etc.) takes physical form, what best describes when it is copyrighted? *CHOOSE ONE ANSWER.*

O Immediately
O After you apply for copyright through the U.S. Copyright Office
O After you hire a lawyer to help you apply for copyright
O After you submit a fee and a copy of your original creation to the U.S. Copyright Office

24. You want to include the ideas from the following quotation from ***School Sports News*** in your research paper. Which of the following options below demonstrates the correct use of paraphrasing?

Citation: Krenkle, Cory M. "Soccer's New Status." ***School Sports News*** 2 Feb. 2007: 16.

"Soccer is quickly gaining popularity in America. More schools continue to add soccer to their list of competitive varsity sports. In fact, most high schools that offer varsity soccer have a feeder program in the elementary and intermediate grades so that players come to the sport with a good number of skills and knowledge of the rules of the game."

CHOOSE ONE ANSWER.

O According to Krenkle, soccer has become very popular in America, partly due to the fact that there are elementary and middle school soccer teams that prepare children to play in high school.

O Soccer's increasing popularity in America is seen in the increasing number of high schools that offer it as a varsity sport. In order to have participants with an understanding of the rules and basic skills, these school districts offer soccer to their younger students (Krenkle 16).

O Most high schools that offer varsity soccer have a feeder program in the elementary and intermediate grades so that players come to the sport with a good number of skills and knowledge of the rules of the game (Krenkle 16).
O "Soccer is quickly gaining popularity in America. More schools continue to add soccer to their list of competitive varsity sports" (Krenkle).

25. You are preparing to create a bibliography for your research paper. Using information from the first page of a book as given below, which of the following is the book's publisher? *CHOOSE ONE ANSWER.*

Three Nights in August

Strategy, Heartbreak, and Joy Inside The Mind of a Manager

Buzz Bissinger

Houghton Mifflin Company

Boston, New York, 2005

O Three Nights in August
O Three Nights in August: Strategy, Heartbreak, and Joy Inside
the Mind of a Manager
O Buzz Bissinger
O Houghton Mifflin Company

Post-test

1. You must plan menus for a nutritious breakfast, lunch, and dinner for one day based on the USDA MyPlate. Select the correct order for these research steps:
   A. Locate appropriate resources.
   B. Create a final version of the menus.

C. Determine the focused topic of your research.
D. Review the success of your research and final menus.
E. Evaluate and record information from a variety of resources.
F. Organize information and create a rough draft version of your menus

CHOOSE ONE ANSWER

O E F C A D B
O A E C F B D
O C A E F B D
O A C E F D B
O C A F E B D

2. If you wanted to find all the books written by J. K. Rowling, what type of search would you choose? *CHOOSE ONE ANSWER.*
O title
O author
O subject
O keyword

3. If you need to know what chapters are in a book, which part of the book provides the best information? *CHOOSE ONE ANSWER.*
O cover of the book O glossary O introduction O table of contents

4. If you end a search term with a special symbol, such as: child$ or child*, you would retrieve results that contain which of the following words?
CHOOSE ONE ANSWER
O Childhood and children
O Chill and child
O Children and toddlers

5. If you wanted to search for a topic that has several synonyms (for example, young people, adolescents, teenagers, teens), which search operator would you use?
CHOOSE ONE ANSWER.
O adj
O and
O near
O not
O or

6. Read the original topic and the revised topic. Is the revised topic broader or narrower than the original topic? Initial Topic: What are the effects of plate tectonics on California?

Revised Topic: What are the effects of the 1994 earthquake on California?

CHOOSE ONE ANSWER.

O Broader

O Narrower

7. Consider the topic below as a possible topic for a three-page research paper. Indicate whether the statement would be a Good Topic, a Topic Too Broad for this paper, or a Topic Too Narrow for this paper.

List the locations for voting in a small town.

CHOOSE ONE ANSWER.

O Good Topic

O Topic Too Broad

O Topic Too Narrow

8. You have just been assigned "the influences of Roman architecture on modern American architecture" as a research topic in your art class. Which group of people could best help you narrow your topic?

CHOOSE ONE ANSWER.

O Art teacher, architect, bricklayer

O Interior decorator, architect, school or public librarian

O Architect, art teacher, school or public librarian

O Bricklayer, interior decorator, school or public librarian

9. When you research a topic, it is important to know its relationship to other concepts. Which word or phrase represents the broadest (most general) subject under which all of the other topics would fit?

CHOOSE ONE ANSWER.

O Chickenpox

O foodborne

O treatment

O illness

O Waterborne

O influenza

10. When students are assigned a topic, it is often quite broad. Thus, it is a student's

responsibility to focus the topic into a more manageable one.

Which of the following does not follow the pattern of broad topic (on the far left) reduced to a narrower topic (on the far right)?

CHOOSE ONE ANSWER.

O Driving while drunk--laws--support group for alcoholics

O School policy--dress code-benefits of having a dress code

O Sports—baseball—steroid use in Major League Baseball

O Disease—cancer—leukemia

11. If you were researching the topic of "fuel cells", which group of tools would be the most useful?

CHOOSE ONE ANSWER.

O Online thesaurus such as ***Merriam-Webster Online Thesaurus*** and online encyclopedia such as ***Britannica Online***

O Science database such as Access ***Science*** and an Internet search engine such as ***Google***

O Health science database such as ***CINAHL,*** online map generator such as ***MapQuest***

12. Which of the following is a characteristic of a primary source?

CHOOSE ONE ANSWER.

O It is created only after other trustworthy works have been consulted.

O It is an interpretation or analysis of an original record.

O It is peer-reviewed for historical accuracy before it is published.

O It is created by those who are involved in or observe the event

13. You just learned your favorite author has a new book out. Where could you most likely check out a copy? *CHOOSE ONE ANSWER.*

O hospital library O public library O government library O museum library

14. Which of the following is not a search engine operator (also known as a Boolean operator)?

CHOOSE ONE ANSWER.

O and

O or

O not

O same

15. You have chosen a project in science class that will require you to locate up-to-date facts about the planets. Which of the following resource choices would you make?

CHOOSE ONE ANSWER.

O encyclopedia and world atlas

O website and almanac

O science textbook and world atlas

O dictionary and website

O bibliography and encyclopedia

16. When you are assessing a website's currency, which of the following would you not examine? *CHOOSE ONE ANSWER.*

O The date the website was created

O Whether the website has information that is not mentioned on other websites

O The date the website was updated

O Hyperlinks to make sure they are working properly

17. When you are assessing a website's authority, which of the following would you not examine? *CHOOSE ONE ANSWER.*

O The author's background and qualifications

O The amount of information provided

O The name and reputation of the sponsoring agency or organization

O The domain name of the URL (ex: .edu, .com, .org)

18. Being information literate means being able to identify when two or more sources agree and disagree. Read the two paragraphs below. Which paragraph discusses this information: Secondhand smoke kills people.

Author #1

The latest studies indicate that death rates for smokers are two to three times higher than for non-smokers at all ages. This means that half of all smokers will eventually die as a result of their smoking. If current smoking trends persist, nearly 9% of the world's population will eventually die as a result of tobacco.

Author #2

Many people still do not believe smoking causes serious health risks. In addition to respiratory illnesses, secondhand smoke causes 3,000 cancer fatalities each year. If people continue to smoke at the current rate, a huge number of these smokers will bring about their own death. At least five out of every ten will die

CHOOSE ONE ANSWER

O Discussed only by Author #1.

O Discussed only by Author #2.

O Discussed by both authors.

O Discussed by neither author

19. The Cattle Producers International placed the following quote on their website:
"Mad cow disease occurs in animals located in small, defined areas. Government measures to restrict the movement of cattle or even to destroy those in a larger region are not necessary and limit farmers' freedom to make their own decisions. Farmers are able to handle problems within their own herds."
Which of the following best reflects the credibility of this source?
CHOOSE ONE ANSWER.
O This is a credible source because it is from the Cattle Producers International website.
O This is a credible source because the information is written as a quote, indicating this is an expert opinion.
O This is not a credible source because the Cattle Producers International is likely to be biased about this issue.
O This is not a credible source because it disregards government policy.

20. As part of a team research project for a biology class, you find an article about the effect of oil spills on marine mammals. The article is protected by copyright. Under copyright law you are allowed to make a copy of the article for your own personal use and:
CHOOSE ONE ANSWER.
O Make 30 copies to distribute on campus for a student group campaigning against pollution.
O Make 4 copies for your next team member meeting.
O Make 4 copies to sell to your classmates who have offered to pay you to do their research.

21. What is the best definition of freedom of speech?
CHOOSE ONE ANSWER.
O the right to expression of personal views or opinions
O the prevention of cheating by students
O the method for seeking permission to share ideas publicly
O the limiting of access to ideas and information that some people find objectionable
O the support of the Bill of Rights

22. Is it legal for you to use images created by another person on your own Web page?
CHOOSE ONE ANSWER.
O Yes, if the creator gives permission.

O Yes, if you scan the image yourself.
O Yes, if you alter the image.
O No, it is not legal for you to use images created by another person on your own Web page

23. You want to include the ideas from the following quotation from the ***Farm News Bulletin*** in your research paper.

Which of the following options below demonstrates the correct use of paraphrasing?
Citation: Helms, Martha R. "Drought Casualties." ***Farm News Bulletin*** 15 Aug. 2007: A4.
"The entire state of Oklahoma has not seen a drop of rain in six weeks. Fields have deep chasms in their arid soil;
the mouths of these chasms gape open, begging for a drink. Farmers have lost billions of dollars worth of crops,
and the lack of feed for livestock is making many more farmers nervous about the winter months."
CHOOSE ONE ANSWER.
O Arid Oklahoma fields have deep chasms that beg for a drink of rain. Farmers are really worried about their livestock.
O Oklahoma has not seen a drop of rain in six weeks. Farmers have lost billions of dollars worth of crops, and the lack of feed for livestock is making many more farmers nervous about the winter months.
O In Oklahoma, "farmers have lost billions of dollars worth of crops, and the lack of feed for livestock is making many more farmers nervous about the winter months" (Helms A4).
O The lack of rain in Oklahoma the past six weeks has caused crop loss valued in the billions and has worried farmers about whether they will be able to feed their animals during the winter (Helms A4).

24. Which of the following terms means correctness in every detail, precision, and exactness?

CHOOSE ONE ANSWER
O coverage
O objectivity
O currency
O accuracy
O authority

25. You are preparing to create a bibliography for your research paper. Using information from the first page of a book as given below, which of the following is the book's title?

Three Nights in August

Strategy, Heartbreak, and Joy Inside The Mind of a Manager

Buzz Bissinger

Houghton Mifflin Company

Boston, New York, 2005

O Three Nights in August
O Three Nights in August: Strategy, Heartbreak, and Joy Inside the Mind of a Manager
O Buzz Bissinger
O Houghton Mifflin Company

Appendix C

Category Definition of TRAILS

Category	Definition	Number of items
Develop topic	"Recognize the hierarchical relationships of broader and narrower topics. Identify individuals to help you focus a topic. Identify manageable topics based on the parameters of an assignment" (From http://www.trails-9.org/viewAssessments2.php?g=9)	5
Develop, use, and revise search strategies	"Understand how to use a given type of information container in order to retrieve information (ex: index and table of contents in a book, an online catalog, etc.). Select search terms. Develop a search strategy for the topic appropriate to a given finding tool. Understand how to use Boolean operators. Revise search strategies when too few, too many, or irrelevant results are returned." (From http://www.trails-9.org/viewAssessments2.php?g=9)	5
Evaluate sources and information	"Recognize bias. Differentiate between fact and opinion. Determine the accuracy, authority, coverage, currency, and relevancy of information and/or information sources." (From http://www.trails-9.org/viewAssessments2.php?g=9)	5
Identify potential sources	"Understand the types of containers in which information is housed (ex: different types of libraries, books, databases, online catalogs, primary sources, etc.) and the types of information that can be found within each type of container. Understand the roles and limitations of differing types of information sources (encyclopedias, atlases, dictionaries, etc.) and finding tools (research databases, online catalogs, bibliographic citations, people, etc.). Select the most productive information sources and finding tools to address a given information need." (From http://www.trails-9.org/viewAssessments2.php?g=9)	5
Recognize how to use information responsibly, ethically, and legally	"Recognize how to paraphrase correctly. Understand the concept of intellectual property (especially copyright, fair use, and plagiarism). Understand the concept of intellectual freedom. Create bibliographies and parenthetical citations according to an appropriate style manual." (From http://www.trails-9.org/viewAssessments2.php?g=9)	5

Appendix D

Argumentation Skills Test

A passage (retrieved from http://darwin.bio.uci.edu/sustain/global/sensem/S98/Tomongin/Report.html) is presented below.

Read it and answer the questions.

"In 1970, a strict measure aimed at reducing air pollution was created. This measure, named the Clean Air Act of 1970, set a national goal to clean the air and reduce harmful emissions across the country in order to protect the lives of the American public. It established the first specific responsibilities for government and private industry to reduce emissions from vehicles. Although the Clean Air Act of 1970 has helped to clean up the air, increased urban development has created new pollution sources and challenges. For example, people are driving more cars more miles on more trips than 1970. Secondly, many people live far from where they work. Since public transportation is not adequate in most areas across the country, people are resorting to commuting to and from work. Finally, auto fuel has become more polluting. As lead was being phased out, gasoline refiners changed gasoline formulas to make up for octane loss, and the changes made gasoline more likely to release smog-forming volatile organic compounds (VOCs) into the air. Examples of volatile organic compounds are carbon monoxide, carbon dioxide, particulates, and some air toxins such as benzene and formaldehyde. To meet the new challenges of urban development and to further enhance the cleansing of our country's air, amendments to the Clean Air Act were made in 1990. Title II, Part C of the 1990 Clean Air Act pushed for the production of clean fuel vehicles in highly polluted areas. Since Southern California has among the worst air in all of the country, the emphasis in the production of clean fuel vehicles took on new meaning. The passing of the Clean Air Act in 1990 initiated action from the California Air Regulatory Board (CARB) to create supplementary laws which, as a result, pushed car manufacturers to design and produce electric powered vehicles.

The goal of electric vehicles is to reduce air emissions associated with typical internal combustion vehicles (ICVs), thereby decreasing the emission of environmentally damaging products such as carbon dioxide and nitrogen oxides. Since electric vehicles run on electricity generated from batteries and do not emit air pollutants, there vehicles are termed zero emission vehicles (ZEV). CARB mandated that ZEVs be 2% of the total automotive sales by 1998 and 10% by 2003."

Question: Why (or why not) is the widespread use of zero emission vehicles a method to improve air quality?

Please write below, your answer (claim) to the question. Back your claim up with evidence from the paragraph above.

Appendix E

Rubric for Argumentation Skills (Excerpt from McNeill & Krajcik, 2006, p. 28, used with permission)

Component	Levels		
	0	1	2
Claim – An assertion or conclusion that answers the original question.	Does not make a claim or makes an inaccurate claim.	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence – Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim).	Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support claim.
Reasoning – A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate and sufficient scientific principles.	Does not provide reasoning, or only provides reasoning that does not link evidence to claim.	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.

Appendix F

Interview for Information Literacy and Argumentation Skill

- What is your name? And what is your stakeholder?

- How did you find information for problem-solving?

(Possible following questions)

- Could you tell me about your information searching strategy?
- Could you describe the difficulties you faced finding information?
- How did you decide on search terms while performing searches?
- How could you judge the accuracy of information?

- How did the real data and information obtained from Virtual Field Trips help you understanding air quality and devise the solution for air pollution?
  (Possible following questions)
- What do you think about the difficulty in learning through Virtual Field Trips?
- Could you explain about how you used Virtual Field Trips to gather the information to solve air quality issues?

- How have your thoughts about information changed from the beginning to the end of the unit?
  (Possible following questions)
- Could you increase your problem solving confidence during the unit?
- What role did the *Connection Log* and *Virtual Field Trips* play in your search for, and evaluation and use of information?

- How did you make your claims for problem-solving?

  (Possible following questions)
- Why are you certain that your claims can solve Air quality issues?
- What were some of difficulties you faced while making the claims?
- How did you consider the perspective of stakeholders while making the claims?
- How did you utilize the data and information you gathered for creating your claims?
- How did the *Connection Log* help you make your claims?

CURRICULUM VITAE

Nam Ju Kim
(January 2017)

Department of Instructional Technology and Learning Sciences
Emma Eccles Jones College of Education and Human Services
Utah State University
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Education

Ph.D. Utah State University, Logan, UT — August 2012-Present; Successfully defended in September, 2016
Major: Instructional Technology and Learning Sciences
Advisor: Dr. Brian R. Belland
Multiple paper dissertation consisting of the following papers:

- "Optimal Challenge in Problem-based learning"
- "Bayesian Meta-analysis: Effectiveness of Computer-based Scaffolding"
- "The Effects of Virtual Field Trips on Students' Information Literacy and Argumentation Skills in Problem-based Learning"

M.A. Yonsei University, Seoul, S. Korea — March 2005-August 2007
Major: Educational Technology
Advisor: Dr. Myung Geun Lee
Thesis: ▪ Effects of MMORPG-based English Instruction for Elementary Students in Korea

B.A. Yonsei University, Seoul, S. Korea — March 1998-Febrary 2005
Major: Education, Liberal Arts

Academic Appointments

In U.S.A (2012 ~ Current)

Secretary/Treasurer — April 2015-Present (a three-year term)
Problem-Based Education Special Interest Group,
American Educational Research Association

Research Assistant, Utah State University, Logan, UT — August 2012-Present

- NSF CAREER
- NSF REESE
- Seed Program to Advance Research Collaborations, Utah State University

Instructor, Dept. of Instructional Technology & Learning Sciences, Utah State University, Logan, UT — January - May 2016

Courses: ▪ ITLS 6205 (graduate level)- Computer Applications in Instruction & Teaching

▪ ITLS 5205 (undergraduate level)- Computer Applications in Instruction & Teaching

Teaching Assistant, Dept. of Instructional Technology & Learning Sciences, Utah State University, Logan, UT

- Role: Curriculum design, Teaching, Grading, and Discussion

Courses	
▪ ITLS 6870 (graduate level)- Current Issues Seminar	January - May 2016
▪ ITLS 6245 (graduate level)- Interactive Multi-Media Production	August-December 2015
▪ ITLS 5245 (undergraduate level)- Interactive Multi-Media Production	August-December 2015
▪ ITLS 6530 (graduate level)- Design and Development Studio	January-May 2013
▪ ITLS 6540 (graduate level)- Learning Theory	August-December 2012

Mentorship, Dept. of Instructional Technology & Learning Science, Utah State University, Logan, UT — January 2015-Present

-Undergraduate Research Assistant

▪ Jacob Piland (Dept. of Computer Science), 16.05.01-Present

▪ Brett Whitney (Dept. of Statistics), 15.01.04- 15.21.31

▪ Lindi Andreasen (Dept. of Teacher Education), 15.01.04- 15.12.31

In South Korea (1999-2011)

President, Edu-point Corporation**,** Seoul, S. Korea — November 2008-April 2011

-Training new employees in a government agency, commercial enterprises, and non-profit organizations
-Human Resource Consulting
-Development of educational programs for adults
-Private academy to teach K-9 students in STEM education

Instructor, Dept. of Early Childhood Education, Ansan College, Ansan, S. Korea — July-December 2008

Courses: ▪ Instruction to Educational Philosophy and History

Researcher, The Institute of Continuing Education, Yonsei University, Seoul, S. Korea — July 2007-July 2008

Research Assistant, The Institute for Educational Research, Yonsei University, S. Korea — March 2005-Febrary 2007

Teaching Assistant, Dept. of Education, Yonsei University, Seoul, S. Korea — March-July 2007

Courses: ▪ Educational Technology Media

Vice Chairman of Student Council
Dept. of Liberal Arts, Yonsei University, Seoul, S. Korea — March 1999- February 2000

Research

Research Projects	Impact of Scaffolding Characteristics and Study Quality on Learner Outcomes in STEM Education: A Meta-analysis. National Science Foundation (REESE Program). PI: Dr. Brian Belland	August 2013-Present
	CAREER: **Supporting Middle School Students' Construction of Evidence-based Arguments.** National Science Foundation (DRK12 Track). PI: Dr. Brian Belland	August 2013-Present
	Computer-based Individualized and Customized Supports for K-12 Students: The Development of Machine Learning Systems. The Seed Program to Advanced Research Collaborations (SPARC). PI: Dr. Brian Belland	January 2017-Present
	Canvalytics Research at Utah State University: Analyzing Usage Data from Interactions with the Canvas Learning Management System. The Seed Program to Advanced Research Collaborations. Utah State University. PI: Dr. Andrew Walker	August 2014- January 2016
	Smart Robot Application Development Project. SK Telecom Corporation. PI: Dr. Yanghee Kim	January-May 2013
	The Physical Activities Data Project. National Science Foundation. PI: Dr. Victor Lee	August-December 2012
	Implementation Plans for internet College Entrance Educational Program. Gangnam district office, Seoul, S. Korea. PI: Dr. Myung Geun Lee	January-December 2008
	A Study of Effectiveness of Educational Game. EbriSoft Corporation, Seoul, S. Korea. PI: Dr. Myung Geun Lee	January-December 2007
	Development of Personality & Aptitude Test for Hotel Employment, Westin Chosun Hotel, Seoul, S. Korea. PI: Dr. Myung Geun Lee	January-May 2007
	Curriculum and Learning Material Development for Regional Innovation. Korea Productivity	January-December 2006

Center, Seoul, S. Korea. PI: Dr. Myung Geun Lee

Design of User Interface for Optimal Web Access of the Visually Impaired. HaSang Rehabilitation Center, Seoul, S. Korea. PI: Dr. Myung Geun Lee — January-December 2006

Peer-Reviewed Articles and Proceedings

Belland, B. R., Walker, A. E., **Kim, N.**, & Lefler, M. (In Press). Synthesizing results from empirical research on computer-based scaffolding in STEM education: A meta-analysis. *Review of Educational Research*. doi:10.3102/0034654316670999 (Impact Factor: 5.235, Ranked #2 out of 231 in Education & Educational Research)

Belland, B. R., Gu, J., **Kim, N.,** & Turner, D. J. (2016). An ethnomethodological perspective on how middle school students addressed a water quality problem. *Educational Technology Research & Development*, *64*, 1135–1161. doi:10.1007/s11423-016-9451-8 (Impact factor: 1.171, Ranked #75 out of 231 in Education & Educational Research)

Choi, H., Lee, J. E., **Kim, N. J.**, …. & Recker, M. (2016). Applying data mining methods to understand user interactions within learning management systems: Approaches and lessons learned. *Journal of Educational Technology Development and Exchange, 8*(2), 99-116.

Kim, N. J., Belland, B. R., & Walker, A. E. (2016). Effectiveness of computer-based scaffolding for K-adult students in the context of problem-centered instructional models related to STEM education: Bayesian meta-analysis. *Proceedings of selected research and development presentation at the 2015 Annual Convention of the Association for Educational Communication and Technology* (vol. 1, pp. 109-116). Indianapolis, IN: AECT.

Yuan, M., **Kim, N. J.**, Drake, J. Smith, S., & Lee, V. R. (2014), Examining how students make sense of slow-motion video. *Proceedings of selected research and developing presentations at the 2014 Annual Convention of International Society of the Learning Sciences* (pp. 1617-1618). Boulder, CO: ICLS

Kim, Y., Smith, D., **Kim, N. J.**, & Chen, T. (2014). Playing with a robot to learn English vocabulary. *KAERA Research Forum, 1*(2), 3-8.

Ke, F., Im, T., Xue, X., Xu, X., **Kim, N. J.**, & Lee, S. (2013). The experience of adult facilitators in a virtual-reality-based social interaction program for children with autism: A phenomenological inquiry. *The Journal of Special Education.* doi: 10.1177/0022466913498773. (Impact Factor: 1.415, Ranked #13 out of 39 in Education, Special)

Suh, S., Kim, S. W., & **Kim, N. J.** (2010). Effectiveness of MMORPG-based instruction in elementary English education in Korea. *Journal of Computer Assisted Learning, 26*(5), 370-378. doi: 10.1111/j.1365-2729.2010.00353.x. (Impact Factor: 1.679, Ranked #35 out of 231 in Education and Educational Research) – Master's thesis

Manuscripts Under Review

Kim, N. J., Belland, B. R., & Walker, A. E. (Under Review). Effectiveness of computer-based scaffolding in the context of problem-based learning for STEM education: Bayesian meta-analysis. Manuscript submitted for publication to *Educational Psychology Review*

Kim, N, J. & Belland, B. R. (Under Review). Enhancing high school students' information literacy and argumentation skills through computer-based scaffolding in problem-based learning for science learning. Manuscript submitted for publication to *American Educational Research Journal*

Kim, N. J. & Belland, B. R. (Under Review). Achieving Optimal Challenge in Problem-based Learning. Manuscript submitted for publication to *Educational Technology Research and Development*

Kim, N. J., Belland, B. R., Walker, A., & Piland J. (Under Review). Computer-based scaffolding in the context of problem-centered instructional models for STEM education across countries and U.S. states: Meta-analysis and cluster analysis. Manuscript submitted for publication to *Comparative Education Review*

Kim, N. J., Kim, K. J., & Kim, S. W. (Under Review). Can computer pointing game improve the visual perception ability of children with intellectual disability? Manuscript submitted for publication to *The Turkey Online Journal of Educational Technology.*

Belland, B. R., Walker, A. E., & **Kim, N. J.** (Under Review). Bayesian network meta-analysis to synthesize the influence of contexts of scaffolding use on cognitive outcomes in STEM education.

Manuscript submitted for publication to *Review of Educational Research*.

Walker, A. E., Belland, B. R., **Kim, N. J.,** & Lefler, M. R. (Under Review). Searching for structure: A Bayesian network meta-analysis of computer-based scaffolding research in STEM education. Manuscript submitted for publication to *Educational Psychologist*.

Gu. J., Belland, B. R., Weiss, D. M., Piland, J. & **Kim, N. J.** (Under Review). Middle School Students' Science Interest and Epistemic Aims in a Technology Enhanced, Problem-based, Scientific Inquiry Unit. Manuscript submitted for publication to *Computers & Education*.

Belland, B. R., Gu, J., **Kim, N. J.,** Turner, D. J., & Weiss, D. M. (Under Review). The relationship between problem-based learning, epistemic beliefs, and argumentation in middle school science: An exploratory, mixed method study. Manuscript submitted for publication to *Instructional Science*.

Manuscripts In Progress

Kim, N. J. & Belland, B. R. Scaffolding middle school students' epistemological beliefs for argumentation skills in problem-based learning.

Kim, N. J. Suggestion of advanced Problem-based Learning in the workplace.

Kim, N. J., Andrew, A. E., Belland, B. R., & Lefler, M. R. Performing network meta-analysis on studies with a mean difference in STATA.

Lefler, M. R., Belland, B. R., Walker, A. E., & **Kim, N. J.** From the ground up: A comprehensive theoretical framework for computer-based scaffolding.

Refereed Presentations

Kim, N. J., Belland, B. R., Walker, A., & Piland, J. (Accepted). Computer-based Scaffolding in STEM Education across Countries and the U.S. States: Meta-analysis and Cluster Analysis. Paper accepted for presentation at the American Educational Research Association 2017 Annual Convention, San Antonio, TX.

Piland, J., **Kim, N. J.,** Belland, B. R., & Walker, A. (Accepted). Effects on Computer-based Scaffolding in Problem-centered Approach for Engineering Education. Paper accepted for presentation at the

American Educational Research Association 2017 Annual Convention, San Antonio, TX.

Walker, A. Belland, B. R., **Kim, N. J.** & Lefler, M. (Accepted). Examining Computer Based Scaffolding Research Quality through a Risk of Bias Lens. Paper accepted for presentation at the American Educational Research Association 2017 Annual Convention, San Antonio, TX.

Belland, B. R., **Kim, N. J.**, Weiss, D., Gu, J., & Piland, J. (Accepted). Impact of Using a Generic Argumentation Scaffold in Two Successive PBL units on Different Topics. Paper accepted for presentation at the American Educational Research Association 2017 Annual Convention, San Antonio, TX.

Belland, B. R., Walker, A. E., **Kim, N. J.,** & Piland, J. (2016, December). New directions for development of and research on computer-based scaffolding emanating from meta-analyses of scaffolding. Paper accepted for presentation at the 2016 Asia History, Philosophy, and Science Teaching Group (HPST) Conference, Busan, South Korea.

Kim, N. J. (2016, October). Bayesian Meta-analysis of Effects on Several Forms of Computer-based Scaffolding in Problem-based Learning. Paper presented at the 2016 Meeting of the Association for Educational Communications and Technology, Las Vegas, NV.

Kim, N. J., Belland, B. R., & Walker, A. E. (2016, October). Suggestion of Machine Learning Systems for Computer-based Scaffolding. Paper presented at 2016 Meeting of the Association for Educational Communications and Technology, Las Vegas, NV.

Kim, N. J. (2016, April). Suggestion of Machine Learning Systems for Computer-based Scaffolding. Poster session at 2016 Students Research Symposium, Utah State University, Logan, UT.

Kim, N. J. (2016, April). Enhancing High School Students' Information Literacy through Computer-based Scaffolding in Problem-based Learning for Science Learning. Paper presented at the American Educational Research Association 2016 Annual Convention, Washington, DC.

Belland, B. R., **Kim, N. J.,** Walker, A. E., Lefler, M., Whitney, B. M., & Andreasen, L. (2016, April). Using Network Meta-analysis to Synthesize Research on Computer-based scaffolding In STEM education. Paper presented at the American Educational Research Association 2016 Annual Convention, Washington, DC.

Andreasen, L., **Kim, N. J.,** Lefler, M., Belland, B. R., & Walker, A. E. (2016, April). Meta-analysis Comparison of Effectiveness of Computer-based Scaffolding in Complex Problem Solving: Individual vs Group Delivery. Paper presented at the American Educational Research Association 2016 Annual Convention, Washington, DC.

Choi, H., Hong, W. J., **Kim, N. J.**, Lee, J. E., Lee. K., Lefler, M., Louviere, J., Recker, M., M., & Walker, A. E. (2016, April). Applying Data Mining Methods to Understand User Interactions within Learning Management Systems: Approaches and Lessons Learned. Round table session at the American Educational Research Association 2016 Annual Convention, Washington, DC.

Belland, B. R., Gu, J., Weiss, M., & **Kim, N. J.** (2016, April). An Examination of Credit Recovery Students' Use of Computer-based Scaffolding in a Problem-based, Scientific Inquiry Unit. Paper presented at the American Educational Research Association 2016 Annual Convention, Washington, DC.

Andreasen, L., **Kim, N. J.**, Lefler, M., Belland, B. R. & Walker, A. E. (2016, March). Meta-analysis Comparison of Computer-based Scaffolding Targeting Individuals versus Groups in Complex Problem Solving. Paper presented at 2016 the Utah Conference on Undergraduate Research, Salt Lake City, UT.

Whitney, B. M., Lefler, M., Andreasen, L., Belland, B. R. **Kim, N. J.**, & Walker, A. E. (2016, March). A Meta-analysis of Computer-based Scaffolding in Sub-domains of Mathematics and Science. Paper presented at 2016 the Utah Conference on Undergraduate Research, Salt Lake City, UT.

Belland, B. R., Walker, A. E. **Kim, N. J.,** & Lefler, M. (2015, November). *Meta-analysis Results Detailing the Effectiveness of Computer-Based Scaffolding in Problem- centered STEM Curricula: Suggestions for Classroom and School Application.* Teacher Education Council Featured TALK: Webinar at Society for Information Technology and Teacher Education.

Kim, N. J. & Belland, B. R. (2015, November). *Effectiveness of computer-based scaffolding in problem-centered instructional models for STEM education: Bayesian meta-Analysis*. Paper presented at 2015 Meeting of the Association for Educational Communications and Technology, Indianapolis, IN.

Belland, B. R., Gu, J., **Kim, N. J.,** & Weiss, M. (2015, April). *The relationship between problem-based learning, epistemic beliefs, and argumentation in middle school science*. Paper presented at the American Educational Research Association Annual Convention, Chicago, IL.

Belland, B. R., Walker, A., **Kim, N. J.,** & Lefler, M. (2015, April). *Synthesizing results from empirical research on computer-based scaffolding in STEM education: A meta-analysis*. Paper presented at the American Educational Research Association Annual Convention, Chicago, IL.

Gu, J., Belland, B. R., **Kim, N. J.**, & Weiss, M. (2015. April). *Middle school students' science interest and epistemic beliefs in a technology enhanced, problem-based, scientific inquiry unit*. Paper presented at the American Educational Research Association Annual Convention, Chicago, IL.

Kim, N. J. & Belland, B. R. (2014, November). *Optimal challenge in problem-based learning*. Paper presented at the Association for Educational Communications and Technology Annual Convention, Jacksonville, FL.

Lefler, M., Belland, B., Walker, A., & **Kim, N. J.** (2014, November). *From the ground up: A comprehensive theoretical framework of computer-based scaffolding*. Paper presented at the Association for Educational Communication and Technology Annual Convention, Jacksonville, FL.

Belland, B. R., Walker, A. E., **Kim, N. J.,** & Lefler, M. R. (2014, July). *A preliminary meta-analysis on the influence of scaffolding characteristics and study and assessment quality on cognitive outcomes in STEM education*. Poster presented at the 2014 Annual Meeting of the Cognitive Science Society, Québec City, Québec, Canada.

Yuan, M., **Kim, N. J.,** Drake, J., Smith, S., & Lee, V. (2014, June). *Examining how students make sense of slow-motion video*. Paper presented at the 2014 meeting of the International Conference of the Learning Sciences, Boulder, CO.

Belland, B., Gu, J., Turner, J., **Kim, N. J.,** & Weiss, M (2014, April). *How middle school students investigated water quality, evaluated evidence, and constructed arguments: An ethnomethodological study*. Paper presented at the American Educational Research Association Annual Convention, Philadelphia, PA.

Ke, F., Im, T., Xue, X., Xu, X.,Lee, S., & **Kim, N. J.** (2013, April). *Facilitating social interactions in a virtual world for children with autism*. Paper presented at the American Educational Research Association Annual Convention, San Francisco, CA.

Kim, Y., Gulz, A., Silvervarg, Y., Haake, M., Chen. T., & **Kim, N. J.** (2013, April). *The effect of the visual gender of an embodied agent: A cross-cultural comparison*. Paper presented at the American Educational Research Association Annual Convention, San Francisco, CA.

Kim, N. J., Kim, S. W., & Lee, M. G. (2006, October). *Effects of Educational Games*. Paper presented at International Conference of the Institute for Educational Research, Yonsei University, Seoul, S. Korea.

Kim, N. J., & Lee, M. G. (2005, June). *Movies and Instructional Technology*. Paper presented at 50-year anniversary Conference of the foundation at the Institute for Educational Research, Yonsei University, Seoul, S. Korea.

Courses Taught

Utah State University, Logan, UT
Department of Instructional Technology & Learning Sciences

ITLS 6205 (graduate level)/5205 (undergraduate level) – Computer Application in Instruction & Teaching (Format: Online and Face-to-Face, Semester: Spring 2016); Topics include pedagogical approaches like technology integration such as assessment (e.g., Qualtics, Google forms, SurveyMonkey), Content Management (e.g., Canvas, Moodle, Wordpress), and Media Production (e.g., Photoshop, InDesign, Audacity, iMovie)

ITLS 6870 (graduate level) – Current Issues Seminar (Format: Online, Semester: Spring 2016); Topics include trends, definitions, types of scaffolding, and current controversies

ITLS 6245 (graduate level)/5245 (undergraduate level) – Interactive Multi-Media Production (Format: Online and Face-to-Face, Semester: Fall 2015); Topics include the usage of advanced software to develop instructional tools such as UNITY (3D game development platform) and Adobe Flash.

ITLS 6530 (graduate level) – Design and Development Studio (Format: Face-to-Face, Semester: Spring 2013); Topics include the utilization of instructional design in various fields

ITLS 6540 (graduate level) – Learning Theory (Format: Face-to-Face, Semester: Fall 2012); Topics include the differences between the behaviorist, cognitivist, and sociocultural paradigms of learning, the application of those concepts to the design of learning environments.

Ansan College, Ansan, South Korea
Department of Early Childhood Education

ECE 1200 (undergraduate level) – Educational Philosophy and History (Format: Face-to-Face, Semester: Fall 2008); Topics include Existential philosophy, Phenomenology, Hermeneutics and Confucianism.

Yonsei University, Seoul, South Korea
Department of Education

EDU4126 (undergraduate level) – Educational Technology media (Format: Face-to-Face, Semester: Spring 2007); Topics include the utilization of computers, learning management systems, and computerized instructional tools.

Awards and Academic honors

Nominated as Graduate Researcher of This Year (2016-2017) Final Decision: April, 2017
: At the Level of College (Emma Eccles Jones College of Education and Human Services

ITLS Doctoral Student Research of This Year (2016-2017)
Utah State University, Logan, UT — January 2017

ITLS scholarship (awarded for academic excellence)
Utah State University, Logan, UT — 2013 fall semester
2014 spring semester
2014 fall semester

The Kelly Foundation Scholarship
Florida State University, Tallahassee, FL — August 2012

The Ruby Diamond Fellowship

Florida State University, Tallahassee, FL — August 2011

Scholarship (awarded for academic excellence)
Yonsei University, Seoul, S. Korea — 2004 fall semester, 2005 spring semester, 2005 fall semester, 2006 spring semester, 2006 fall semester

Certificate of Recognition
outstanding contribution to Education for Guro citizens
Guro district office, Seoul, S. Korea — July 2007

Certificate of Recognition
outstanding contribution to Education for Jongro citizens
Jongro district office, Seoul, S. Korea — March 2007

Certification

- **Certificate of Completion for International Teaching Assistants** — August, 2012
  Recommended for a teaching assistantship as a classroom instructor or lab instructor (advanced level)
  - The Intensive English Language Institute
  - Utah State University, Logan, UT
- **Teaching Certification** — August, 2011
  - Program for Instructional Excellence
  - Florida State University, Tallahassee, FL

Computer Skills

Statistical software: SPSS, STATA, SAS, MPLUS, Minitab, WINBUGS, R.

Qualitative research tool: NVivo

Adobe products: Photoshop, Illustrator, Flash, Premier

Programming languages: Javascript, HTML, CSS

Gaming Engine: 3D unity

Data Analytics: Matlab, Waikato Environment for Knowledge Analysis (WEKA)

Research Methodologies

- Quantitative method
  - Nonparametric statistics
  - Generalized Linear Models
  - Multilevel Modeling
  - Structural Equation Model
  - Bayesian Analysis
  - Advanced Missing Data Imputation

- Qualitative method
  - Ethnography
  - Grounded Theory
  - Phenomenology
  - Phenomenography