A Meta-Synthesis of CSCL Literature in STEM Education

Jessica McKeown, Indiana University, jeschamb@indiana.edu
Cindy E. Hmelo-Silver, Indiana University, chemelosi@indiana.edu
Heisawn Jeong, Hallym University, heis@hallym.ac.kr
Kylie Hartley, Indiana University, hartley2@indiana.edu
Roosevelt Faulkner, Indiana University, rtfaulkn@indiana.edu
Navo Emmanuel, Indiana University, nemmanue@indiana.edu

Abstract: This research aims to synthesize the extensive literature on Computer Supported Collaborative Learning (CSCL) in STEM education published between 2005-2014. Our synthesis focuses on the interactions of collaboration, technology, and pedagogies to see how different combinations may contribute to learning. A Latent Class Analysis was used to categorize existing research and points to a six-cluster solution. We have synthesized across and within the three largest clusters to 1) help us identify robust themes in this field and 2) help us better understand the positive outcomes associated with these aspects of CSCL in STEM education. The results suggest that different combinations of technology, pedagogy, and collaboration types require different strategies to scaffold students' learning. This research provides a frame for synthesizing the effects of CSCL in synchronous and asynchronous STEM education and with various technologies and pedagogical designs.

Visions of technology as a social entity are now ubiquitous and tout collaborative learning as a key benefit (Roschelle, 2013). There is extensive research regarding the use of CSCL in science, technology, engineering, and mathematics (STEM) education (Stahl et al., 2014; Jeong, Hmelo-Silver, & Yu, 2014). Many individual studies have reported encouraging results with different types of technologies used in a range of pedagogical approaches, with different forms of collaboration. Roschelle, Bakia, Toyama, and Patton (2011) have argued that we need to understand the "compound resources" at play in complex learning environments. However, there has been little systematic review on the impact of CSCL, especially ones focusing on the interactions of collaboration, technology, and pedagogies used (Jeong & Hmelo-Silver, 2016; Kirschner & Erkens, 2013). To understand the impact of CSCL research, it is important to examine the evidence based on the effectiveness of CSCL with both CSCL and measures of effectiveness broadly defined. Research in CSCL and the learning sciences should be especially well positioned to examine the complexity of these learning environments given the emphasis on mixed methods and design-based research (Jeong, Hmelo-Silver, & Yu, 2014; Roschelle et al., 2011), but as Kirschner and Erkens (2013) point out, we are not there yet. The editors of *ijCSCL* have recently noted that CSCL is becoming a mature field and that we need to understand the landscape of the field (Ludvigsen, Cress, Law, Rosé, & Stahl, 2016).

Theoretical framework

Our work uses meta-synthesis as a frame for reviewing research, allowing for the integration of research across qualitative and quantitative studies, and combinations of evidence across multiple studies (Suri & Clark, 2009; Bair, 1999). One of the strengths and challenges of this type of analysis is that it compares research that may not have common metrics. Research in CSCL focuses on learning as a cognitive and/or social process and studies learning designs, learning processes, and pedagogic practices that support technology-mediated collaborative processes in communities of practice. CSCL research is guided by a variety of theoretical frameworks that include information processing, social constructivist, sociocultural, social psychology, and communication theories (e.g., Jeong, Hmelo-Silver, & Yu, 2014; O'Donnell & O'Kelly, 1994). This synthesis cuts across theoretical frameworks to focus on how different combinations of technology, approaches to collaboration, and pedagogy contribute to learning, as these are the pillars of CSCL. Technologies that promote learning through collaboration mirror major shifts in education, which characterizes learning as being social and collective rather than individual. The changing pedagogies that support these perspectives and evolving technologies have merged to create many new CSCL opportunities in classrooms (Jeong & Hmelo-Silver, 2016; Miyake, 2007). Jeong and Hmelo-Silver (2016) have recently theorized that technology needs to have particular affordances to support CSCL. These include 1) establishing a joint task, 2) communication, 3) sharing resources, 4) engaging in productive processes, 5) engaging in co-construction, 6) monitoring and regulation, and 7) finding and building groups and communities. These affordances can be realized when the interactions of technology, pedagogy, and modes of collaboration are considered. Our work considers this complex nature of CSCL and seeks synthesis within these interactions.

Methods

Data sources

To guide our systematic review of CSCL literature in STEM domains, we defined CSCL as two or more people using technology to work together toward a shared learning goal, and used this definition while searching and screening papers. We searched through two databases, ERIC and Web of Science, in addition to seven key journals regarded by experts to be major outlets for publishing CSCL research (Jeong, Hmelo-Silver, & Yu, 2014). Over 1,500 qualitative and quantitative papers focusing on various education levels published between 2005-2014 were screened to ensure each paper met the following criteria: (a) STEM education, (b) empirical research. Of the screened papers, 708 papers met our criteria and were then coded for a range of study characteristics; educational level, collaboration type, pedagogy, and technology (e.g., Jeong et al., 2014). Inter-rater reliability was checked by having two members of the research team independently code 20% of the sample. Kappas were satisfactory ranging from .76-.82. This data was then submitted to an LCA analysis, described next.

Sampling approach using LCA analysis

To identify and characterize groups of similar cases we used LCA, Latent Class Analysis (Hagenaars & McCutcheon, 2002; Linzer & Lewis, 2011). LCA is a technique to find latent subgroups in the data based on the co-occurrence of variables. LCA takes the coded data and assigns each row a cluster membership by selecting the highest posterior probability of that row across all clusters. To classify the papers into one and only one cluster, the original posterior probabilities are used with the highest probability selected. As the number of clusters is unknown, several models are fit and one is selected per fit indices. Our results show that the Akaike Information Criterion (AIC) as well as the Negative Log Likelihood Ratio (Deviance) pointed at a six-cluster solution, which is shown in Table 1 below. Space precludes additional details regarding the LCA analysis. Clusters were named based on dominant themes in the cluster.

Table 1: Description of the six clusters with overall frequencies, percentage of total articles and sample size.

Clusters	Cluster Description	N (% of total)	# of Articles Sampled
1. Mediated Inquiry with Dynamic Feedback	Collaboration: Mediated Pedagogy: Inquiry and exploration learning Technology: Dynamic tools or miscellaneous tools	246 (34%)	22
2. Teacher-directed Synchronous Collaboration	Collaboration: Synchronous Pedagogy: Teacher-directed Technology: Synchronous communication	74 (10%)	10
3. Synchronous Exploration and Construction	Collaboration: Synchronous Pedagogy: Discussion or inquiry and exploration learning Technology: Synchronous communication	51 (7%)	7
4. Mixed Tools and Pedagogies	Collaboration: Asynchronous or synchronous Pedagogy: Other Technology: Groups and communities	38 (5%)	4
5. Asynchronous Teacher-directed Discussion	Collaboration: Asynchronous Pedagogy: Discussion or teacher-directed Technology: Asynchronous communication	154 (21%)	18
6. Generative Asynchronous Inquiry	Collaboration: Asynchronous or mediated Pedagogy: Inquiry and exploration learning or teacher-directed Technology: Sharing and co-construction	145 (20%)	11

To sample a subset of the paper for more in depth analysis, a stratified random sampling technique was used (Sampath, 2001). A stratified random sampling technique takes the size and variability of the subgroups in the data, in our case, clusters. Because all variables in this analysis are categorical, the Average Deviation Analog (ADA) was employed to compute the variability of the clusters (Wilcox, 1973). The sample size and the ADA's were used to feed into an Optimal Allocation algorithm, which is a class of stratified random sampling techniques that accounts for differences in size and variability among clusters (Sampath, 2001). As Table 1 indicates, clusters 1, 5, and 6 are the most robust in terms of size and multiple iterations of the analysis with different subsets of articles. In this paper, we present the synthesis for these three clusters given (a) they are the most common and (b) space limitations that preclude including the smaller clusters here.

Synthesis findings

We identified the dominant themes that emerged in each cluster. In this process, we took note of the educational levels of the studies in each cluster as they can be an important moderator of CSCL.

Cluster 1: Mediated inquiry with dynamic feedback

This cluster (sample n = 22) emphasizes face-to-face mediated collaboration with inquiry and exploration pedagogies using dynamic technological tools (e.g. tools that provide a response to user actions) such as immersive technology, games, and simulations. This cluster also represents papers using a variety of miscellaneous technological tools such as mobile devices, open-source software to conduct remote controlled experiments, and digital game design software. More than half of papers in this cluster were coded as K-12 (59%), which was highest percentage for K-12 education among the six clusters, suggesting this combination of pedagogy and technology is more common in K-12 than combinations in other clusters. Sampled studies reported that learning under these conditions led to significant learning gains, positive student engagement, meaningful interactions between students, and improved group collaboration and communication skills.

What may have led to such significant learning gains and positive engagement? One overarching theme in this cluster is guided instruction, with varying levels of guidance ranging from open-ended to highly structured suggestions (Avraamidou, 2013; Chiang, Yang, Hwang, 2014; Jaakkola & Nurmi, 2008; Kong et al., 2009; Kuo et al., 2012; Loke et al., 2012; Santos-Martin et al., 2012; Lai & White, 2012; Tsa et al., 2012; Yang, & Chang, 2013). Closely related to this theme of guided instruction is immediate feedback and discussion; participants at a variety of educational levels received immediate feedback from facilitators (Avraamidou, 2013; Kong et al., 2009; Lantz, & Stawiski, 2014; Santos-Martin et al., 2012), peers (Chen, et al., 2012; Chiang et al., 2014; Gallardo-Virgen, & DeVillar, 2011; Kuo, Hwang, & Lee, 2012; Lai & White, 2012), and/or software (Chen, et al., 2012; Dzikovska, et al., 2014; Echeverría et al., 2012; Holmes, 2007; Roschelle et al., 2010; Loke, et al., 2012; Nelson & Ketelhut, 2008). For example, as students engaged in problem-based learning (PBL), facilitators provided assistance and feedback throughout the learning processes (Avraamidou, 2013; Santos-Martin, et al., 2012).

Working with authentic problems and materials was also common in this cluster (Avraamidou, 2013; Chiang et al., 2014; Loke, et al., 2012; Tsai, et al., 2012). Using real materials along with a simulation tool also proved to be an effective way to use CSCL for improved learning and positive student engagement (Jaakkola & Nurmi, 2008; Kong, Yeung, & Wu, 2009; Santos-Martin et al., 2012). In one instance, students using virtual simulation tools were guided to explore their own ideas and test them against models (Li et al., 2006), thus encouraging learning through mistakes while minimizing risks. Simulation tools also afforded students more opportunities to conduct experiments compared with using real apparatus (Kong et al., 2009). Similarly, augmented reality games allowed students to play with concepts and ideas (Echeverría et al., 2012). Together, simulated tools or augmented reality games allowed students opportunities to practice and redesign without great demand on time, money, or physical tools. In sum, learning with authentic problems was supported by guided instruction and immediate feedback from the tools and discussion in this cluster. The role of technology was in helping students to work in more authentic settings and have opportunities to directly test their ideas and solutions, with the tools providing dynamic feedback.

Cluster 5: Asynchronous teacher-directed discussion

The Asynchronous Teacher-Directed Discussion cluster (sample n = 18) represents papers emphasizing asynchronous collaboration, discussion, or teacher-directed pedagogies and asynchronous communication technology such as discussion boards, a knowledge forum, or email. Many of these sampled papers included a variety of types of collaboration, pedagogies, and/or technologies in addition to those that are emphasized in the cluster description shown in Table 1. Most papers in this cluster were coded as higher education (70%), suggesting that this combination of CSCL is quite common at that level. Most papers within this cluster focused on trying out new learning management systems and collecting student feedback, not learning outcomes.

Articles within this cluster primarily focus on online learning environments and the characteristics of these environments that promote learning, thus justifying the sense that researchers and educators alike seek to better understand the technology that best supports this type of learning environment. For example, papers in this cluster studied new learning management systems (Lopez-Morteo & Lopez, 2007; Yang & Liu, 2007), assessment for distance learning users (van Aalst & Chan 2007), student satisfaction with a virtual environment (So & Brush 2008), or with specific communication tools (Overbaugh & Casiello, 2008). Within this cluster, researchers studied how learners participated and interacted within an online discussion forum (Swigger, Hoyt, Serçe, Lopez, & Alpaslan, 2012; Vercellone-Smith, Jablokow, & Friedel, 2012; Manca, Delfino, & Mazzoni, 2009; van Aalst, 2009), how assigning group roles or tutors affected student learning within an online platform (De Wever et al., 2010), and how group size impacted participation and learning a new programming language (Shaw, 2013). Other papers focused on learning gains of users in an asynchronous learning environment (Lakkala, Lallimo, & Hakkarainen, 2005), and building skills necessary for collaborative engagement in an asynchronous course (Yukawa, 2006; Žavbi, & Tavčar, 2005). Discussion forums have an important role in these kinds of online environments; they provide a space for reflection in which students interpret and talk about the problems and tasks at hand, but also space for some personal contacts. One of issues that emerged from our synthesis of this cluster is the "single pass" strategy that students may use in discussion forum assignments. Students often made contributions to a discussion topic, but moved on from the topic before a conclusion was made (Hewitt, 2005). Such strategies can cause premature closure or death of threads before the issues have been fully explored and efforts are needed to address students' use of such strategy.

Our synthesis also indicated that asynchronous collaboration seems to be most effective when collaboration and communication are flexible (e.g. students are able to use both synchronous and asynchronous communication tools, or students can choose which modes of communication and/or collaboration to use; Yang & Liu, 2007; Lopez-Morteo & Lopez, 2007; Yukawa, 2006), when there is embedded support and scaffolds (Lakkala, Lallimo, & Hakkarainen, 2005; Martínez, Del Bosch, Herrero, & Nuño, 2007), when roles are assigned or chosen (De Wever et al., 2010; Lin, Lin, & Huang, 2008), and when good communication practices are established within a group (So & Brush, 2008; Swigger et al., 2012). In sum, synthesis of research in this cluster suggests that learning in online environments requires attention to several issues such as group size, available communication channels, and communication practices and strategies with the platforms. As in cluster 1, teacher guidance is important, particularly in providing feedback and in supporting desired communication practices.

Cluster 6: Generative asynchronous inquiry

This cluster represents papers emphasizing asynchronous and mediated collaboration with inquiry and exploration or teacher-directed pedagogies that use sharing and co-construction or integrated environmental technologies (sample n=11). Papers in this cluster were coded as 26% K-12 and 69% higher education. Such inquiry and exploration pedagogies used within this sample include project-based learning (Pifarre & Cobos, 2010) and case-based learning (Hämäläinen & Arvaja, 2009; Vicari, Flores, Seixas, Gluz, & Coelho, 2008). Meanwhile, teacher-directed pedagogies include problem solving (Krause, Stark, & Mandl, 2009), blended learning (Goktas, & Demirel, 2012; Hämäläinen, & Arvaja, 2009; Neumann, & Hood, 2009), and distance learning (Inayat, Amin, Inayat, & Salim, 2013). Knowledge building is a common pedagogy guiding instruction among these sampled papers, whether in addition to using an inquiry and exploration pedagogy like PBL (Pifarre, & Cobos, 2010). or simply using knowledge building pedagogy on its own (Huang, & Nakazawa, 2010; Marée, van Bruggen, & Jochems, 2013). The technology used in knowledge building is very much co-constructive in this sample. Such sharing and co-construction technologies used among these sampled papers include participatory technology (Goktas, & Demirel, 2012; Huang, & Nakazawa, 2010; Neumann & Hood, 2009) and representational tools (Marée, van Bruggen, & Jochems, 2013). By their nature, integrated environments offer instructors and students a variety of tools that can be used asynchronously or in mediated face-to-face environments. Therefore, it is no surprise to see this technology used in collaboration spaces. Among these sampled papers using integrated environments, we see one emphasized asynchronous collaboration (Pifarre & Cobos, 2010), one emphasized mediated collaboration (Krause, Stark, & Mandl, 2009), and one that incorporated both types of collaboration (Inayat, Amin, Inayat, & Salim, 2013). Other sampled papers include those that used case-based pedagogies, but with other technology such as intelligent tutoring (Vicari, Flores, Seixas, Gluz, & Coelho, 2008) or other software (Hämäläinen & Arvaja, 2009).

In another example from this cluster using a wiki co-construction environment, students reported more interaction with peers than their instructor, indicating that this technology can help instructors move into a facilitator role (Huang & Nakazawa, 2010). In doing so though, students noted how it is important that when the instructor/facilitator does want to communicate with students about revising their work, they do so in the co-constructive environment. Meanwhile, a major conclusion of Marée, van Bruggen, and Jochems (2013) is the possibility for undergraduate science students to learn more with less guidance from teachers by using multimedia enriched concept maps with built-in instructions for collaboration. Second, this sample of CSCL literature also offers some promising implications about specific technologies and pedagogical practices. When students participate in asynchronous discussion, particularly when they engage as student-facilitators, it is important that they understand the different types of thread patterns and how questioning, summarizing, pointing and resolving may affect discussion thread development and closure (Chan et al., 2009). Pedagogically, in ICT courses, it is important to integrate the technology being discussed so participants better understand not only its purpose, but also how to use it from a first-hand perspective (Goktas & Demirel, 2012). Finally, Krause et al., (2009) support the notion that feedback may promote more reflection, especially when it offers explanations that encourages deeper understanding, therefore, feedback whether that be from software or the instructor should be thoughtful and thorough and encourage students to think beyond remembering information.

Like cluster 5, many of these sampled papers investigated how students used and perceived specific technology. The conclusions that emerged from these sampled papers tended to emphasize perceptions of co-construction or integrated environmental technologies in the classroom rather than learning outcomes. These conclusions suggest that the use of collaborative group activities, instructors' timely feedback, and support materials embedded within an integrated system all related to student satisfaction with a variety of STEM related vocational e-learning courses, (Inayat, et al., 2013). The articles that did focus on student outcomes suggest that we can draw conclusions about technology supports for learning that encourages specific positive outcomes such as improved metacognitive skills (Pifarre & Cobos, 2010) and positive student engagement and classroom attendance (Neumann & Hood, 2009). Similar to the finding in cluster 1, when guided instruction and immediate feedback are integrated within these specific pedagogies and technologies, it can lead to improved student learning (Krause, Stark, & Mandl 2009; Marée, van Bruggen, & Jochems, 2013) and task completion (Hämäläinen, & Arvaja, 2009).

Results, however, indicated that there is a delicate balance between too much and not enough feedback or guidance. Consistent with the findings in other clusters, a lack of feedback can negatively affect students' learning outcomes (Krause, Stark, & Mandl 2009). Meanwhile, too much feedback can lead to discussion thread premature closure (Chan, Hew, & Cheung, 2009). Without enough guidance or clarity regarding the importance of positive collaboration, students may have high task activity, but not necessarily good collaboration (Hämäläinen, & Arvaja, 2009). In sum, student perception of asynchronous inquiry CSCL is overall positive. Timely guidance from teachers also play an important role in increasingly student learning outcomes as well as favorable perception of the environment, but the results also highlight the importance of keeping the guidance at an optimal level.

Discussion

Through a synthesis effort, this research has attempted to fill a gap in the CSCL literature. By focusing on the relationships among technologies, pedagogies, and types of collaboration in these complex learning environments, we address the concerns raised by Roschelle et al. (2011) and Kirschner and Erkens (2013). The results show how these facets of CSCL interact as well as themes that cut across educational levels.

Using the combination of face-to-face mediated collaboration, inquiry and exploration pedagogies with dynamic or other technologies allow teachers to move lessons beyond the traditional classroom into other learning spaces that may provide more situated learning experiences where students are still engaged in face-to-face communication. This type of instruction may lead to learning gains, positive engagement, and promote meaningful interactions between students across STEM domains and education levels; however, it does appear to be more common in K-12 educational research. While these technologies have the potential to make learning meaningful, relevant, and interesting, there are some things to consider before employing this type of CSCL in the STEM classroom. CSCL researchers and teachers need to design guided instruction that allows the student to explore the content and receive positive and regular feedback, whether through the technology, in person directly, or through student peers. Another consideration is that CSCL environments such as these can be very resource intensive; learning spaces need to have access to all necessary technologies as well as space for face-to-face mediated collaboration that encourage inquiry and exploration pedagogies.

The use of asynchronous technologies and collaboration methods along with the teacher-directed and discussion pedagogies allows teachers and students to learn and interact with more flexibility surrounding when, where, and how they elect to participate; something that seems to be more common in higher-education perhaps simply because this flexibility is not afforded to many K-12 learners. This type of learning may lead to learning gains and help students build skills necessary to successfully engage cooperatively in an asynchronous course. However, to be an effective learner in distance education using asynchronous collaboration, learners need to be capable of self-regulating, something that may be more challenging for younger learners. Another issue, particularly in graded discussion forums, is students moving on from a conversation before a conclusion is made. This ultimately leads to difficult questions being passed over and might contribute to poor integration across course topics. Using CSCL effectively requires considering many different combinations of technology, pedagogy, and ways of collaborating. As such, professional development is critical for supporting teachers on strategies to integrate these components of CSCL for effective classrooms that promote positive student outcomes.

Finally, the literature reviewed offers some promising implications for a broad range of combinations of technologies, pedagogies, and types of collaboration. First, it suggests how the interaction of these technologies with inquiry and exploration pedagogies can help support instructors in their move toward a facilitator role and thus encourage students to be active and constructive among themselves. Second, this literature suggests that asynchronous pedagogy needs to be scripted or have some type of guidance embedded for students to stay engaged and informed. Third, instructors take on a facilitator role in most of these learning environments, which may require some training regarding knowing when to guide students toward resources or lets students grapple with ideas they are struggling with. More generally, across these clusters, opportunities for learner agency are important, whether working on authentic tasks or in having opportunities to choose communication/collaboration modes. Similarly, support and guidance for collaboration appear to be a necessary condition for CSCL effectiveness across all six clusters, although the exact forms of guidance are likely to differ by the age of the learners and with online compared with face-to-face settings.

To further explicate under what conditions technology may support learning in STEM education CSCL, we are conducting additional analyses to identify relationships between collaboration, technology, and recently proposed seven affordances of CSCL technology for learning (Jeong & Hmelo-Silver, 2016). We believe this will provide a more nuanced look at the mechanics behind each identified cluster. The next step to come in this research in terms of research and practice would be to carefully detail how this meta-synthesis can directly impact classroom practices.

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Acknowledgements

This work was funded by National Science Foundation Grant #DRL-1439227. Conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We thank Alejandro Andrade for his able assistance with Latent Class Analysis.