DEVELOPING COLLABORATIVE SKILLS THROUGH STEM APPROACH

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Collaborative learning is a practice that dates back centuries. In Confucius' classic text, Li Ji, there is a famous saying that one becomes narrow-minded when learning without friends (Juanjuan, 2013). Therefore, collaborative skills not only allow students to interact with others (Hesse et al., 2015), but also enhance their opportunity to learn, which differs significantly from individual learning. Collaborative problem-solving is crucial in science, technology, engineering, and math (STEM), which are fraught with complex challenges like climate change, overpopulation, welfare, resource management, health, and biodiversity (L. Chen et al., 2019). For example, to address the current COVID-19 pandemic, policymakers need to collaborate with experts from different fields, specifically scientists, health workers, and the media, to create and implement effective policies and strategies.

Preparing the youths with a collaborative mindset is crucial for addressing the issues and difficulties that arise in real life. There is also an increasing demand for new collaborative forms due to the widespread application of modern digital tools and social networking platforms. Common scenarios today in both in-school and out-of-school environments may include (1) a community of gamer discussing mechanisms to solve emerging technical bugs; (2) a small team working in an online chat room to solve a math problem; and (3) a class using discussion boards asynchronously to brainstorm ideas on a science topic (Kelley et al., 2020). This review specifically focuses on developing technology-based collaborative skills through STEM approach to reflect the trend of integrating technology into education.

A. Parameters and Strengths of Collaborative Skills

This section adopts Dillenbourg's broad definition of collaborative skills, which refers to a situation where two or more people learn or attempt to learn something together (Dillenbourg, 1999). In theory, these skills are based on social constructivism that learning occurs during social interaction (Vygotsky, 1978). Meanwhile, in practice, the key to defining specific forms of collaborative skills is to determine their various pragmatic parameters:

1. The scale of collaborative skills can range from as small as a couple to a large community. The timing can vary, such as in a year-long course or a one-time activity (for example, a team-building activity in a company).
2. The setting can change from physical collaborative skills to virtual learning.
3. The medium can include various technology platforms and others (Lai, 2011).

Besides these pragmatic parameters, the dynamics of collaborative skills are influenced by various forces, such as the preference for individualism or collectivism in relation to learning objectives. When learning goals are established for individuals, collaborative skills prioritize improving individual knowledge or skills. In the PISA test, the OECD defines students' collaborative problem-solving competence as the capacity of individuals to effectively engage in a process, where two or more agents attempt to solve a problem (OECD, 2015). This involves sharing the understanding and effort required to achieve the solution, as well as pooling their knowledge, skills, and efforts towards achieving the solution.

In short, when learning is oriented towards collective purposes, community building and collective knowledge construction are prioritized. The concept of 'team-based learning' focuses on small group interactions in a classroom setting and requires that assignments promote team development alongside individual learning (Michaelsen et al., 2008). Similarly, advocates of 'communities of practice' (Wenger et al., 2011) or knowledge building (Chan et al., 2006) emphasize the importance of building communities among students. Communities of practice are groups of people who share a common concern or passion for what they do, and regularly interact to learn how to do it better (Wenger et al., 2011). Knowledge building emphasizes collective knowledge creation and innovation as well as prioritizes the advancement of community knowledge over individual achievement (Scardamalia & Bereiter, 2006).

Another force that influences collaborative skills is the division of work. In many learning scenarios, the teacher organizes the work division, where tasks are divided into independent sub-tasks, and the group assembles the different parts together (Nugraha et al., 2019). Collaborative learning is often utilized in these cases. On the other hand, in other collaborative skills opportunities, work is not divided but rather negotiated and completed by the individuals involved (Micari & Pazos, 2021).

All group members contribute to the same learning task in a collaborative learning environment. In contrast, in a competitive environment, students work independently and strive to outperform others. However, collaboration and competition do not have to contradict each other. Contradictions can serve as a driving force in advancing the activity system (Froehle & Roth, 2004). Similarly, competition can be a positive element for collaborative skills (Ziegler & Hamker, 2011). This often occurs alongside of collaborative within or across group learning settings (S.-Y. Chen & Liu, 2018). A competitive mindset can be a double-edged sword and can facilitate collaborative problem-solving processes when carefully crafted and well-utilized.

B. Benefits of Collaborative Skills in STEM Education

Collaborative skills have been well-embraced in STEM education (Thibaut et al., 2018). Building student learning communities is recommended to increase student interest and persistence in STEM programs in schools (Sithole et al., 2017). Several meta-analysis studies have shown that collaborative skills promote student learning in general (J. Chen et al., 2018; Kyndt et al., 2013). Moreover, a more recent meta-analysis revealed that collaborative skills supported by computer technology have demonstrated notable effectiveness in STEM education, specifically in process, knowledge, and affective outcomes (Jeong et al., 2019).

More importantly, the study provides compelling evidence that collaborative skills effectively address critical issues in STEM education (Laal & Ghodsi, 2012). One such issue is low enrollment and high interest (X. Chen & Soldner, 2013; Lichtenberger & George-Jackson, 2013; Romash, 2019; Sithole et al., 2017). Collaborative skills have the potential to increase students' self-esteem and sense of achievement by allowing them to help others and involving them in the design of classroom activities. Students can develop HOTS (Higher Other Thinking Skills) and learn better in STEM content through collaborative skills than individual learning (Gokhale, 1995). In addition, collaborative skills can foster students' communication skills to resolve conflicts (Tolmie et al., 2010).

Another issue is equity in STEM education. Female students generally have lower enrollment rates but higher dropout rates in STEM majors compared to male students. Similarly, students from low-income families show similar patterns compared to high-income families (X. Chen & Soldner, 2013; Lichtenberger & George-Jackson, 2013). Previous studies have shown that students' satisfaction with the positive experience of collaborative skills makes them more intrinsically interested in learning. This has consequently made them more willing to attend school and persist in STEM learning. Moreover, collaborative skills promote communication and interdependence among all group members, regardless of race, gender, and achievement level, leading to a more equitable learning environment (Esmonde, 2009; Panitz, 1999).

C. Collaborative Skills and Technology in STEM Education

Technology plays a crucial role in facilitating collaborative skills. It can provide visual representations of learning tasks, guide collaborative processes, and serve as scaffolding for building collective knowledge (Goodyear et al., 2014). This study focuses on examples of technologies that directly support the collaborative during the learning process. Although some technologies can be used for collaborative skills, they do not play a central role. This is supported by Lee, Drake and Thayne report, where students collected their activity data (e.g., counting steps with time) by wearing sports watches and learned statistics by exploring the data in groups (Lee et al., 2016). The sport watches were solely used for data collection, and not to facilitate collaboration. This type of study is beyond the scope of this chapter.

D. Developing Collaborative Skills through STEM Approach

1. The Environment of Remote Collaborative Skills

Audio and video conferencing tools (e.g., Zoom, Skype) are widely used today in synchronous distance learning settings. These tools provide a means to connect students across space (Pasani et al., 2020), and often include specific features that support collaborative skills, such as screen sharing, chat rooms, and annotations. Babaian and Schiano (2020) provided some practical tips for facilitating small group work in online learning. These skills include encouraging teachers and students to be familiar with features that support small group work by managing display names and changing screen names to group ID/name, navigating between group workspaces and the main space, sending messages to all groups or specific groups in breakout spaces, as well as being familiar with sharing or annotation tools.

Studies have also been conducted to examine these features. For example, Singhal showed how breakout rooms in Zoom could be used in a virtual pharmacotherapy course during COVID-19 (Singhal, 2020). In class, every five to six students were grouped and placed in a breakout room, hence the teacher could move around the room to facilitate discussions. The study emphasized that the use of breakout rooms can assist students' small team tasks in promoting active learning, consequently leading to more participation.

2. Multi-User Virtual Environments (MUVEs)

MUVEs have been used to facilitate collaborative skills. In these environments, students typically use avatars to interact with each other in a virtual world, similar to multiplayer online role-playing games (Barab et al., 2005). These environments can also bring learning benefits to students with autism spectrum conditions (Cheng & Ye, 2010). A pioneering example in science education is River City, a MUVEs learning environment designed to engage middle-grade students in standards-based scientific inquiry practices (https://muve.gse.harvard.edu/) (Tilak et al., 2020).

The curriculum was enhanced through several development versions (Ketelhut et al., 2010). For example, the first unit focuses on biology and ecology. Students can connect through avatars, and investigate an authentic problem (e.g., disease outbreak in a city) in a virtual city with a river running through the environment. In order to solve a problem, students can collaborate by sharing information and communicating with team members about the collected data through a chat text tool. In retrospect, Ketelhut et al. (2010) concluded that MUVEs are viable tools for enabling student-centered collaborative inquiry learning, providing an alternative to more conventional inquiry-based science instruction.

Ibanez et al. proposed a 3D virtual collaborative skills model that guides students' collaborative activities in MUVEs (Ibáñez et al., 2013). The model establishes synchronization learning points to achieve individual or group desired learning goals, as well as work division to promote positive interdependence. Based on the model, students conducted a case study in which participants (through avatars) navigated a 3D environment and collected information related to available theater performances in order to purchase tickets for the shows they wanted to attend. They also performed several collaborative activities, such as information sharing and group assessment. The factors affecting interactive collaboration was identified in the first iteration and the design was refined. This resulted to improved collaboration in the second iteration (Ibáñez et al., 2013).

Unlike the examples mentioned earlier that gave a game-like setting, Hwang and Hu (2013) described a geometry unit for fifth graders, wherein students engaged in various activities within a virtual classroom. In this environment, they were able to manipulate virtual 3D geometric objects, observe their classmates' problem-solving processes, as well as provide feedback and critique to each other. According to their findings, the experimental group outperformed the control group in terms of geometry learning. Moreover, the most effective way for students to acquire abstract geometry ideas is to collaborate with their classmates and practice manipulating virtual objects (e.g., by viewing and critiquing each other's answers) (Hwang & Hu, 2013).

It is note worthy that manipulating virtual items can enhance peer-to-peer interactions in real life. Jackson et al. (2013) designed a math game activity on a table to augment and reinforce what students had learned in their fourth-grade math class. The students were expected to use components from their resource pool to fill in the blanks on a math problem displayed in the center of the table screen (allowing multiple users to edit the content simultaneously). Four students work together in a group, with each possessing resources that could potentially contain important components of the problem-solving solution. They were required to collaborate in order to complete the task. The students responded positively to the collaborative game-based learning exercise. Upon completing the program, male students' arithmetic scores showed substantial improvement .

In conclusion, MUVEs and audio/video conferencing system are examples of mechanisms that connect students online. Although these technologies are now widely used in everyday life, there is still a need for a further empirical studies to determine the exact elements of these tools that can most effectively enable collaborative learning (Warburton & García, 2010). Meanwhile, MUVEs not only provide alternative and shared areas for students to learn, but they also simulate various work environments (Mantziou et al., 2018). Students are likely to feel more engaged in the problem-solving process when they can experience it authentically by exploring virtual environments and interacting with virtual objects.

3. Facilitate Written Discourse in Groups

Tools for audio or video conferencing that make remote communication more convenient and effective, require high-speed internet connection and gadgets equipped with cameras and microphones. In contrast, written discourse can fulfill the needs of collaborative skills without such constraints.

a) Synchronized Discussion Forum

In synchronous discussion forums, students can participate in real-time using written text or symbols (Kuyath, 2008; Rosé & Ferschke, 2016). This type of forum is also known as online chat. Some advanced forms of this forum, designed for educational purposes, incorporate simulated intelligent agents that can offer students real-time feedback on the discussed topics and facilitate communication between participants. According to Wang, Rosé, and Chang, high school students collaborated in pairs in several geology-related brainstorming activities (Wang et al., 2011). They used a synchronous chat program called VIBRANT, which included an integrated virtual agent capable of providing real-time comments.

Using a similar platform called MentorChat and virtual agents, Tegos et al. demonstrated collaborative learning among 96 university students on human-computer interaction (Tegos et al., 2016). In both learning environments, virtual agents appeared as a third person participating in the team dialog, providing comments and asking guiding questions based on their discourse text. Both studies showed the positive effects of virtual agents in improving students' collaborative skills.

b) Asynchronous Discussion Forum

Asynchronous discussion forum allows students sufficient time to analyze the posts made by their peers and provide more useful comments to the forum. This tool provides the benefit of meeting students' requests for rapid interaction and feedback. In an investigation on the effectiveness of collaborative learning in an undergraduate engineering course, the group members were requested to discuss an assigned team task and submit a group report based on their communication through email (Liu et al., 2018).

The web, shared by multiple users, such as blogs, can serve as asynchronous discussion forum to exchange viewpoints. For example, Jimoyiannis and Angelaina (2012) used an educational blog to engage 21 high school students in examining the issue of acid rain. A learning community was established for each student on the blog, where they shared their results and commented on their colleagues' findings. According to the results, students showed increased interest in the activity (Angelaina & Jimoyiannis, 2012).

Through their activities on the blog, the students have shown social and emotional support for each other, leading to increased construction of new information. An investigation into how students collaborate was conducted with a total participation of 25 pre-service teachers who used an asynchronous online whiteboard to communicate with each other (Gressick & Derry, 2010). The students were divided into groups of five and tasked with developing an interdisciplinary education module that included elements of math and science. Each member in the group can upload their design ideas, while others can comment, make suggestions for modifications, and rate them. Although there was no initial work division by the teacher, the students took on different responsibilities and leadership roles (such as seeking input, knowledge contribution, and topic control), which were widely distributed among team members. This occurred even though there was no initial work division by the teacher.

Discussion forums, both synchronous and asynchronous, have been around for quite some time. However, they are constantly evolving with the emergence of new technologies. In recent years, multimodal inputs like audio or video were incorporated into online discourse platforms, such as the Flipgrid app. Moreover, machine-based learning algorithms have been embedded to support automated and customized student feedback (Rosé & Ferschke, 2016).

4. Provide Direction for the Collaborative Processes

The previously mentioned technologies generate more opportunities for students to work together by connecting across different locations and times. Nonetheless, the collaboration may not always be successful due to various reasons, such as inefficient communication, lack of interaction, and inappropriate work division (Le et al., 2018). Affordable collaborative scripts in computer-based learning environments have been investigated as a means to guide collaborative activities. Rummel, Mulins, and Spada used a total of 106 middle school students to investigate scripted collaborative arithmetic learning. They modified a computer-based teaching program called Cognitive Tutor Algebra to include scripts that allowed users to work together (Rummel et al., 2012).

After initially working on separate challenges individually, two students eventually teamed up at a computer to address a challenge presented by a script, integrating their respective problems. During the collaboration, additional scripts emerged to encourage collaborative behavior at specific times (e.g., contributing based on independent problem-solving experience, listening to peers, and asking questions for clarification). The results showed students who followed the scripts demonstrated better collaborative skills and were more successful in finding solutions to problems compared to other groups that did not follow the scripts.

Collaborative scripts have been used for various purposes, including guiding collaborative behavior and a tool for peer monitoring. Bouyias and Demetriadis investigated and compared the effects of mandatory peer monitoring prompts with fading scaffolding scripts in a collaborative argumentation activity in a computer science classroom. The students participated in an online argumentation learning environment called iArgue (Bouyias & Demetriadis, 2012). Random pairs were formed between 34 students who belonged to two different classes. In the peer-monitoring group, when student A submitted a task, peer B would receive the submission along with a peer-monitoring prompt asking them to check whether A's argumentation followed the model. In case it does not, student B was expected to indicate where improvements are needed. The monitoring task should be completed before student B can continue their work. Besides the peer-monitoring prompts, consistent scaffolding scripts were also provided (e.g., guidance on argument construction).

Students in the fading group did not receive any prompts for peer monitoring, instead, they were provided with a fading scaffolding script. This means there was less scaffolding after the students' second post. According to the results, the scripts that encourage peer monitoring significantly improved learning outcomes. In another study that investigated the function of collaborative scripts in argumentative learning, these scripts not only served as peer monitoring prompts, but also guided students to systematically analyze their partner's argumentation and encouraged their argumentative construction. These activities include guiding students to paraphrase, criticize, ask questions, provide counterarguments, and propose new arguments. Another benefit of using collaborative scripts in argumentative learning is that they encourage students to develop their argumentative constructions (Noroozi, Weinberger, et al., 2013).

A total of sixty students participated in the study, each of whom worked with a partner on a task that required knowledge from both of their respective fields of study. Specifically, the partnership consisted of two students, one with a background in water management and the other with a background in international development studies. The texts were successful in facilitating the development of argumentation knowledge (Noroozi, Biemans, et al., 2013).

The results suggest that collaborative scripts can effectively guide and enhance collaborative processes by encouraging collaborative behavior, providing peer monitoring, and facilitating knowledge construction, especially in the collaboration of small-group. This is true for collaborative scripts used in online environments. Consequently, there should be greater emphasis on incorporating collaborative scripts into educational practice, and more studies on methods that enable the collaboration among larger groups.

5. Produce, Store, and Visualize Collective Knowledge

Besides expanding opportunities for collaborative work and providing direction for collaborative processes, technological tools and platforms have also been developed to facilitate the generation and sharing of collective knowledge by the groups. Example of this is Wikipedia, an online encyclopedia that has grown over the past twenty years and currently has over 56 million entries available in more than 300 different language editions (https://en.wikipedia.org/wiki/List of Wikipedias). It has rapidly developed into one of the most popular websites. A concept behind Wikipedia states that anyone can contribute to the world's most comprehensive encyclopedia. This reflects the latest popular advances in humanity's pool of knowledge.

Several examples of Wikipedia and similar technologies are used in educational settings at various levels. Pifarre and Kleine Staarman investigated the collaborative processes that occur when elementary school students work together on a science book in the context of a wiki. The study focused on student-generated writing from a dialogic perspective, considering the number of paragraphs, words, sentences, and reasoning relationships (Pifarré & Kleine Staarman, 2011). This analysis was conducted on student-generated texts, and the conclusion suggests that dialogic methods should be used to examine the process of collaborative interaction. This approach can help create more effective pedagogies related to wiki use in educational settings. Furthermore, a student-centered inquiry learning paradigm has been created and implemented for use in college biology classes as part of the WIKIed Biology project, supported by the National Science Foundation (Frisch et al., 2013).

The students participated by collaboration through the use of Web2.0 technologies, managing and tagging educational resources obtained from the Internet. They collaborated in small groups to create and publish website pages based on their scientific inquiry projects. The results showed that the students significantly improved their understanding of various biological concepts, as well as their ability to think critically and their awareness of the relevance of scientific communication.

Similar to Wikipedia's crowdsourcing model, "citizen science" can be seen as the practice of delegating various scientific endeavors to the general public. The term "citizen science" is used to describe the practice of nonprofessional scientists (such as data collection) by contributing to the generation of professional and scientific knowledge (Bonney et al., 2009). Digital Earth is an initiative that involves individuals in the collection and conversion of information related to the Earth into digital form (Brovelli et al., 2020). OpenStreetMap (www.openstreetmap.org), an example of Digital Earth, is a collaborative effort to produce a free and editable map of the world populated with geographic data provided by individual users. YouthMapper, a student branch of OpenStreetMap, which can be accessed online at www.youthmappers.org, is a global network of students who are actively engaged in collaborative mapping projects using OpenStreetMap. Gama et al. (2019) examined the collaborative mapping experiences of students from three different institutions in Europe, North America and Africa. The study found that participating in Mapathons events ("mapping marathons"), not only improved student's technical ability and subject knowledge, but also enhanced their engagement as socially responsible citizens (Gama et al., 2019).

Knowledge forums, led by Marlene Scardamalia and Carl Bereiter over three decades of study and development, are a pioneering platform for communal knowledge construction in upper-middle-class spaces (Bereiter & Scardamalia, 2014). These forums serve as tools to assist and support groups in developing their knowledge. Students compile their knowledge records in relation to specific subjects. One of the strengths of the forum is the provision of multiple scaffolds that students can use to develop their submissions. For instance, students can start a statement by selecting a pre-defined question, such as "My Theory" or "My Understanding Problem," and can also add comments on top to offer a high-level overview. Empirical studies in the topic have shown that students have found the benefits of Knowledge forums in developing their fundamental, domain-specific, and epistemic literacies (Hong et al., 2016).

The iKOS platform is a web-based knowledge organization tool that enables cross-disciplinary collaborative learning in a classroom environment (Namdar & Shen, 2016). The platform allows students to generate, exchange, and organize information. It also has the benefit of incorporating multimodal features (Jiang et al., 2019, 2020). In Wiki mode, students can create knowledge entries similar to those on Wikipedia, while they can tag and annotate images or photos in PicTag mode. In Mindmapping mode, they can create concept maps to visualize the relationships between big ideas. In Flipbook mode, they can publish their multimodal pages and interactive flipbook to the general public. This activity supports multiple modes of knowledge representation. According to the results, after completing a lesson on nuclear power, prospective science teachers were able to create a rather voluminous knowledge network (Namdar and Shen, 2018).

Personal response systems (such as clickers), and polling applications are other technology categories that attract attention. An instructional technique known as Peer Instruction is established to engage students in typically lecture-based classroom conversations. These resources is often effective with Peer Instruction instructional practices. When using clickers or polling software, it is necessary to project and view the distribution of student responses on the screen. This allows students to be motivated to talk to their neighbors about their decisions and thought processes, as the projection of the class' collective state of knowledge engages them in conversation. This strategy has been proven effective in improving student learning and retention through STEM approach (Watkins & Mazur, 2013).

The platforms mentioned above provide a space for students to store, create and exchange collective knowledge with each other. In addition to improving the community and building knowledge by contributing to the collective knowledge, the students can also benefit from developing their individual knowledge and other personal skills in the process.

E. Evaluation of Technology-based Collaborative Skills through STEM Approach

Despite its widespread use, there is a relatively limited amount of empirical study conducted in evaluating technology-based collaborative skills. The assessment of collaborative learning gained can be viewed from two different perspectives, namely collaborative outcomes and processes. Collaborative outcomes refer to what the group produces during the learning process. This collective output can be analyzed to infer the collaborative processes or individual understanding of teamwork. Meanwhile, the processes examine the complex dynamics (such as social interactions among group members), which serve as a link between the individual and the group.

In order to develop products, the discourse documented has been utilized in various technology platforms during the collaborative learning process. For example, synchronous or asynchronous discussion forums can record the discourse that occurs between members of a learning community. This provides a rich data source for evaluating and analyzing the collaboration and knowledge construction among members.

Jimoyiannis and Angelaina investigated Community of Inquiry (CoI) and Social Network Analysis (SNA), using a total of 131 blog posts that addressed the issue of acid rain (Angelaina & Jimoyiannis, 2012). Through the use of CoI analysis, community characteristics were examined by classifying publications into three categories, namely social presence (i.e., not involving domain knowledge but for emotional communication and group cohesion), cognitive presence (i.e., involving domain knowledge), and teacher presence. Teacher presence was defined as the presence of a teacher in a publication (i.e., including instruction or scaffolding). The SNA analysis provided a quantitative representation of the engagement level of individuals as well as their social relationships. The amount of direct contact each member has with others may indicate the power distribution among students.

The use of external technologies, such as video or audio recordings, to analyze collaborative processes is frequent. This approach can be used to investigate the collaborative processes. Talentino investigated the use of a mixed reality environment to enhance the study of earth science by high school students. The discourse between students and teachers (e.g., questions and answers) as well as among students, were analyzed and coded using video and audio recordings (e.g., comments, questions, or responses between individual students). The statistics revealed a visible increase in the number of statements driven by student participation. This activity is a usual practice for computer-based learning platforms to track students' activities as they use the platform (e.g., time stamps, clicking on buttons or pages, editing text) (Tolentino et al., 2009).

Several previous studies have focused on analyzing log data to gain deeper understanding of collaborative processes within groups. Olsen, Rummel, and Aleven (2019) investigated how elementary school students solve arithmetic problems using an online platform with an intelligent virtual tutor under three different learning conditions, namely collaborative, individual, and combined. They also evaluated the effectiveness of each student's problem-solving approach within the context of their learning conditions by analyzing log data of students' interactions with the virtual tutor. This analysis included students' attempts, errors, and hint requests (Olsen et al., 2019).

Some studies focus on both collaborative procedures and their products. For example, Altebarmakian and Alterman (2019) investigated the extent to which 29 university students engaged in collaborative work during a computer science and psychology class by analyzing the data recorded through the system and the substance of the posts made by the students. The students worked on their assignments in groups of three to five using an educational blog as their platform of collaboration. They were required to independently draft and upload their answers to the initial problem, comment on posts made by others, respond to questions posed by others, modify their solutions in light of the group conversation, and eventually submit final responses (Altebarmakian & Alterman, 2019).

The participation of each student in the group project is assessed with respect to their cognitive, social, and behavioral habits during the activity. The measurement of their reading, editing, and commenting behaviors, as tracked by the system, provides insights into their behavioral engagement. The log data also revealed that students' interaction levels depended on whether they referred to previous statements made by their peers. Subsequently, the level of cognitive engagement was evaluated based on the topics covered in the students' contributions.

An important observation regarding the assessment component of the study on collaborative learning is that most studies use assessments to test the effects on individual students' academic or emotional outcomes. However, these tests do not necessarily reflect the development of students' understanding of collaboration or their ability to work together effectively. Therefore, it is crucial they receive timely and useful feedback on their individual and group efforts when participating in learning activities that require collaboration. Continuous assessment of collaborative learning facilitates meaningful communication, not only among collaborative group members, but also between students and teachers. Therefore, students have a more positive experience when participating in collaborative learning.

F. Conclusion

The limitations, strengths, and advantages of collaborative learning through STEM approach are outlined in this chapter. The chapter also provides examples of technologies that facilitate collaborative skills in various ways, such as connecting students across time and space, encouraging written (and multimodal) discourse among students, guiding collaborative processes, and promoting collective knowledge. Further exploration is needed for formative assessment of students' collaborative knowledge and practices. In addition, the assessment of students' collaborative skills should be explored, with a focus on evaluating the effect of collaborative learning on students' academic and affective outcomes (individual) as well as conducting formative assessment of collaborative knowledge and practice.

REFERENCES

Altebarmakian, M., & Alterman, R. (2019). Design Heuristics to Support Cohesion within Online Collaborative Learning Groups. *2019 IEEE Frontiers in Education Conference (FIE)*, 1–9.

Angelaina, S., & Jimoyiannis, A. (2012). Analyzing students' engagement and learning presence in an educational blog community. *Educational Media International*, *49*(3), 183–200.

Babaian, T., & Schiano, B. (2020). Energize your online course with group work. *HBP*

Higher Education's Inspiring Minds.

Barab, S., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development*, 86–107.

Bereiter, C., & Scardamalia, M. (2014). Knowledge building and knowledge creation: One concept, two hills to climb. *Knowledge Creation in Education*, 35–52.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V, & Shirk, J. (2009). Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977–984.

Bouyias, Y., & Demetriadis, S. (2012). iArgue: A web-based argumentation environment integrating collaboration scripting support and flexible fading techniques. *Educational Technologies for Teaching Argumentation Skills*, 198–224.

Brovelli, M. A., Ponti, M., Schade, S., & Solís, P. (2020). Citizen science in support of digital earth. *Manual of Digital Earth*, 593–622.

Chan, T.-W., Roschelle, J., Hsi, S., Kinshuk, Sharples, M., Brown, T., Patton, C., Cherniavsky, J., PEA, R. O. Y., & Norris, C. (2006). One-to-one technology-enhanced learning: An opportunity for global research collaboration. *Research and Practice in Technology Enhanced Learning*, *1*(01), 3–29.

Chen, J., Wang, M., Kirschner, P. A., & Tsai, C.-C. (2018). The role of collaboration, computer use, learning environments, and supporting strategies in CSCL: A meta-analysis. *Review of Educational Research*, *88*(6), 799–843.

Chen, L., Yoshimatsu, N., Goda, Y., Okubo, F., Taniguchi, Y., Oi, M., Konomi, S., Shimada, A., Ogata, H., & Yamada, M. (2019). Direction of collaborative problem-solving-based STEM learning by learning analytics approach. *Research and Practice in Technology Enhanced Learning*, *14*, 1–28.

Chen, S.-Y., & Liu, S.-Y. (2018). Reinforcement of scientific literacy through effective argumentation on an energy-related environmental issue. *EURASIA Journal of Mathematics, Science and Technology Education*, *14*(12), em1625.

Chen, X., & Soldner, M. (2013). STEM attrition: College students' paths into and out of

STEM fields (NCES 2014-001). Washington, DC: National Center for Education Statistics, Institute of Education Sciences, US Department of Education. *Institute for Education Sciences, US Department of Education*.

Cheng, Y., & Ye, J. (2010). Exploring the social competence of students with autism spectrum conditions in a collaborative virtual learning environment–The pilot study. *Computers & Education*, *54*(4), 1068–1077.

Dillenbourg, P. (1999). *Collaborative learning: Cognitive and computational approaches. Advances in learning and instruction series.* ERIC.

Esmonde, I. (2009). Mathematics learning in groups: Analyzing equity in two cooperative activity structures. *The Journal of the Learning Sciences*, *18*(2), 247–284.

Frisch, J. K., Jackson, P. C., & Murray, M. C. (2013). WikiED: Using web 2.0 tools to teach content and critical thinking. *Journal of College Science Teaching*, *43*(1), 70–80.

Froehle, C. M., & Roth, A. V. (2004). New measurement scales for evaluating perceptions of the technology-mediated customer service experience. *Journal of Operations Management*, *22*(1), 1–21.

Gama, K., Rautenbach, V., Green, C., Gonçalves, B. A., Coetzee, S., Fourie, N., & Sastry, N. (2019). Mapathons and hackathons to crowdsource the generation and usage of geographic data. *Proceedings of the International Conference on Game Jams, Hackathons and Game Creation Events 2019*, 1–5.

Gokhale, A. (1995). Collaborative learning enhances critical thinking. *Journal of Technology Education*, *7*(1).

Goodyear, P., Jones, C., & Thompson, K. (2014). Computer-supported collaborative learning: Instructional approaches, group processes and educational designs. *Handbook of Research on Educational Communications and Technology*, 439–451.

Gressick, J., & Derry, S. J. (2010). Distributed leadership in online groups. *International Journal of Computer-Supported Collaborative Learning*, *5*, 211–236.

Hesse, F., Care, E., Buder, J., Sassenberg, K., & Griffin, P. (2015). A framework for teachable collaborative problem-solving skills. *Assessment and Teaching of 21st Century Skills: Methods and Approach*, 37–56.

Hong, H.-Y., Chen, B., & Chai, C. S. (2016). Exploring the development of college students' epistemic views during their knowledge-building activities. *Computers & Education*, *98*, 1–13.

Hwang, W.-Y., & Hu, S.-S. (2013). Analysis of peer learning behaviors using multiple representations in virtual reality and their impacts on geometry problem-solving. *Computers & Education*, *62*, 308–319.

Ibáñez, M. B., Rueda, J. J. G., Maroto, D., & Kloos, C. D. (2013). Collaborative learning in multi-user virtual environments. *Journal of Network and Computer Applications*, *36*(6), 1566–1576.

Jackson, A. T., Brummel, B. J., Pollet, C. L., & Greer, D. D. (2013). An evaluation of interactive tabletops in elementary mathematics education. *Educational Technology Research and Development*, *61*, 311–332.

Jeong, H., Hmelo-Silver, C. E., & Jo, K. (2019). Ten years of computer-supported collaborative learning: A meta-analysis of CSCL in STEM education during 2005–2014. *Educational Research Review*, *28*, 100284.

Jiang, S., Shen, J., & Smith, B. E. (2019). Designing discipline-specific roles for interdisciplinary learning: two comparative cases in an afterschool STEM+ L program. *International Journal of Science Education*, *41*(6), 803–826.

Jiang, S., Shen, J., Smith, B. E., & Kibler, K. W. (2020). Science identity development: how multimodal composition mediates student role-taking as scientist in a media-rich learning environment. *Educational Technology Research and Development*, *68*, 3187–3212.

Juanjuan, Z. (2013). Confucius as a critical educator: Towards educational thoughts of Confucius. *Frontiers of Education in China*, *8*(1), 9–27.

Kelley, T. R., Knowles, J. G., Holland, J. D., & Han, J. (2020). Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. *International Journal of STEM Education*, *7*, 1–13.

Ketelhut, D. J., Clarke, J., & Nelson, B. C. (2010). The development of River City, a multi-user virtual environment-based scientific inquiry curriculum: historical and design evolutions. *Designs for Learning Environments of the Future: International Perspectives from the Learning Sciences*, 89–110.

Kuyath, S. J. (2008). *The social presence of instant messaging: Effects on student satisfaction, perceived learning, and performance in distance education*. The University of North Carolina at Charlotte.

Kyndt, E., Raes, E., Lismont, B., Timmers, F., Cascallar, E., & Dochy, F. (2013). A meta-analysis of the effects of face-to-face cooperative learning. Do recent studies falsify or verify earlier findings? *Educational Research Review*, *10*, 133–149.

Laal, M., & Ghodsi, S. M. (2012). Benefits of collaborative learning. *Procedia-Social and Behavioral Sciences*, *31*, 486–490.

Lai, E. R. (2011). Collaboration: A literature review. *Pearson Publisher. Retrieved November 11*, 2016.

Le, H., Janssen, J., & Wubbels, T. (2018). Collaborative learning practices: teacher and student perceived obstacles to effective student collaboration. *Cambridge Journal of Education*, *48*(1), 103–122.

Lee, V. R., Drake, J. R., & Thayne, J. L. (2016). Appropriating quantified self-technologies to support elementary statistical teaching and learning. *IEEE Transactions on Learning Technologies*, *9*(4), 354–365.

Lichtenberger, E., & George-Jackson, C. (2013). Predicting High School Students' Interest in Majoring in a STEM Field: Insight into High School Students' Postsecondary Plans. *Journal of Career and Technical Education*, *28*(1), 19–38.

Liu, H., Spector, J. M., & Ikle, M. (2018). Computer technologies for model‐based collaborative learning: A research‐based approach with initial findings. *Computer Applications in Engineering Education*, *26*(5), 1383–1392.

Mantziou, O., Papachristos, N. M., & Mikropoulos, T. A. (2018). Learning activities as enactments of learning affordances in MUVEs: A review-based classification. *Education and Information Technologies*, *23*, 1737–1765.

Micari, M., & Pazos, P. (2021). Beyond grades: improving college students' social-cognitive outcomes in STEM through a collaborative learning environment. *Learning*

Environments Research, *24*, 123–136.

Michaelsen, L. K., Sweet, M., & Parmelee, D. X. (2008). *Team-Based Learning: Small Group Learning's Next Big Step: New Directions for Teaching and Learning, Number 116* (Vol. 103). John Wiley & Sons.

Namdar, B., & Shen, J. (2016). Intersection of argumentation and the use of multiple representations in the context of socioscientific issues. *International Journal of Science Education*, *38*(7), 1100–1132.

Noroozi, O., Biemans, H. J. A., Weinberger, A., Mulder, M., & Chizari, M. (2013). Scripting for construction of a transactive memory system in multidisciplinary CSCL environments. *Learning and Instruction*, *25*, 1–12.

Noroozi, O., Weinberger, A., Biemans, H. J. A., Mulder, M., & Chizari, M. (2013). Facilitating argumentative knowledge construction through a transactive discussion script in CSCL. *Computers & Education*, *61*, 59–76.

Nugraha, F., Siahaan, P., & Chandra, D. T. (2019). The effect of structured individual responsibility on students' achievement increase in cooperative learning science class. *Journal of Physics: Conference Series*, *1157*(3), 32066.

OECD. (2015). *PISA: Scientific Literacy*.

Olsen, J. K., Rummel, N., & Aleven, V. (2019). It is not either: An initial investigation into combining collaborative and individual learning using an ITS. *International Journal of Computer-Supported Collaborative Learning*, *14*, 353–381.

Panitz, T. (1999). *Collaborative versus Cooperative Learning: A Comparison of the Two Concepts Which Will Help Us Understand the Underlying Nature of Interactive Learning.*

Pasani, C. F., Amelia, R., & Hassanhassan, Z. (2020). Covid-19 impact in Indonesia's education sector: Challenges and strategy. *Journal of Advanced Research in Dynamical and Control Systems*, *12*(7 Special Issue), 1722–1731. https://doi.org/10.5373/JARDCS/V12SP7/20202281

Pifarré, M., & Kleine Staarman, J. (2011). Wiki-supported collaborative learning in primary education: How a dialogic space is created for thinking together. *International Journal of Computer-Supported Collaborative Learning*, *6*, 187–205.

Romash, Z. M. (2019). *Leaving STEM: An examination of the STEM to non-STEM major change and how the STEM curriculum relates to academic achievement in non-STEM fields*. Seton Hall University.

Rosé, C. P., & Ferschke, O. (2016). Technology support for discussion-based learning: From computer-supported collaborative learning to the future of massive open online courses. *International Journal of Artificial Intelligence in Education*, *26*, 660–678.

Rummel, N., Mullins, D., & Spada, H. (2012). Scripted collaborative learning with the cognitive tutor algebra. *International Journal of Computer-Supported Collaborative Learning*, *7*, 307–339.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building. *The Cambridge.*

Singhal, T. (2020). A review of coronavirus disease-2019 (COVID-19). *The Indian Journal of Pediatrics*, *87*(4), 281–286.

Sithole, A., Chiyaka, E. T., McCarthy, P., Mupinga, D. M., Bucklein, B. K., & Kibirige, J. (2017). Student attraction, persistence and retention in STEM programs: Successes and continuing challenges. *Higher Education Studies*, *7*(1), 46–59.

Tegos, S., Demetriadis, S., Papadopoulos, P. M., & Weinberger, A. (2016). Conversational agents for academically productive talk: A comparison of directed and undirected agent interventions. *International Journal of Computer-Supported Collaborative Learning*, *11*, 417–440.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., & De Cock, M. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1), 2.

Tilak, S., Glassman, M., Kuznetcova, I., Peri, J., Wang, Q., Wen, Z., & Walling, A. (2020). Multi-User Virtual Environments (MUVEs) as alternative lifeworlds: Transformative learning in cyberspace. *Journal of Transformative Education*, *18*(4), 310–337.

Tolentino, L., Birchfield, D., Megowan-Romanowicz, C., Johnson-Glenberg, M. C., Kelliher, A., & Martinez, C. (2009). Teaching and learning in the mixed-reality science classroom. *Journal of Science Education and Technology*, *18*, 501–517.

Tolmie, A. K., Topping, K. J., Christie, D., Donaldson, C., Howe, C., Jessiman, E., Livingston, K., & Thurston, A. (2010). Social effects of collaborative learning in primary schools. *Learning and Instruction*, *20*(3), 177–191.

Vygotsky, L. (1978). Interaction between learning and development. *Readings on the Development of Children*, *23*(3), 34–41.

Wang, H.-C., Rosé, C. P., & Chang, C.-Y. (2011). Agent-based dynamic support for learning from collaborative brainstorming in scientific inquiry. *International Journal of Computer-Supported Collaborative Learning*, *6*, 371–395.

Warburton, S., & García, M. P. (2010). 3D design and collaboration in massively multi-user virtual environments (MUVEs). In *Cases on collaboration in virtual learning environments: processes and interactions* (pp. 27–41). IGI global.

Watkins, J., & Mazur, E. (2013). Retaining students in science, technology, engineering, and mathematics (STEM) majors. *Journal of College Science Teaching*, *42*(5), 36–41.

Wenger, E., Trayner, B., & De Laat, M. (2011). *Promoting and assessing value creation in communities and networks: A conceptual framework*. Rapport.

Ziegler, R., & Hamker, N. (2011). The idea of a collaborative competition–a case study. *Futures*, *43*(4), 441–449.

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