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Online collaborative learning and cognitive presence in mathematics and science education. Case study of university of Rwanda, college of education

Leonard Nungu[1] · Evode Mukama[1,2] · Ezechiel Nsabayezu[1]

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Abstract

This study aims to investigate how online collaboration can support the learning of science, technology, engineering, and mathematics (STEM) in higher education. Empirical data were collected from 88 postgraduate students studying at the African Centre of Excellence for Innovative Teaching Learning Mathematics and Science (ACEITLMS) using online oral interviews and two five-point Likert scale questionnaires. Interviews were analysed through content analysis while data from the questionnaire were scanned through the Statistical Package for Social Scientists (SPSS) to compute descriptive statistics and Spearman rho correlation coefficient. The findings indicate that online collaborative learning through small group discussions prompt knowledge co-construction, and higher-order thinking skills in STEM subjects. Moreover, the findings demonstrate how several electronic multimedia tools (PhET simulations, animations, YouTube videos) can increase student retention and engagement in learning STEM. Though the students reported that they experienced challenges such as poor internet connection, lack of laboratory work, electricity shortage, and limited ICT skills, they managed to complete STEM learning activities by using free virtual laboratories, portable tethering hotspots from their smartphones, and smartphones where power was a problem and learnt the navigation of ICT tools from their peers. The study found moderate positive Spearman rho correlation coefficient, $r_s = 0.69, P < 0.01$ which explains that 69% of the total variance in the students' successful performance is explained by the two variables, i.e., social and cognitive presence. The study recommends more training for course instructors and students. Efforts should be put in place to focus on ICT manipulation and curating interactive content. The researchers acclaim the expansion of internet coverage in University of Rwanda campuses. This action will enhance online and blended learning. Moreover, the study recommends the integration of ICT and the use of multimedia tools such as Bio-interactive and Physics Education Technology (PhET) interactive simulations in STEM subjects as supplementary resources. These tools support cognitive and affective domains in the teaching and learning process. Furthermore, universities can

Extended author information available on the last page of the article

reduce the problem of expensive and inadequate laboratory equipment by adopting the use of virtual laboratories, especially for online STEM lessons.

Keywords Cognitive presence · Knowledge construction · Rwanda · Social presence · STEM education

1 Introduction

Science, technology engineering, and mathematics (STEM) are pivotal to supporting socio-economic development, international competitiveness, and job opportunity creation. Ismail (2018) supports that STEM education can produce technical experts to work in industries, teaching personnel in colleges and universities and medical doctors just to mention. In a similr vein, Rwanda strongly acknowledges that STEM education in higher education has the potential to boost the socioeconomic transformation of the country. Thus, the country created policies to promote STEM education at all educational levels including higher education (MINEDUC, 2008). In this connection, the country developed a national science, technology, scientific research and innovation policy that aims at integrating science and technology in HIEs with a focus on using ICT education (MINEDUC, 2008). However, most objectives of this policy are yet to be achieved due to challenges met at the implementation level including the scarcity of competent human resources and technical expertise in STEM education (MINEDUC, 2018, 2019, 2022).

Despite the challenges faced at the implementation stage of ICT and STEM education policies, the Ministry of Education (MINEDUC) and the Ministry of Information and Technology Communication (MINI TECH) established smart studios in six higher educational institutions (HEIs) including the University of Rwanda – College of Education (WEHUBIT, 2022). These smart studios aim to leverage the use of ICT in creating interactive digital STEM content that should be delivered through online learning (WEHUBIT, 2022). To this end, not much has been reported using ICT and online learning to promote the teaching and learning of STEM subjects, especially for public HEIs in Rwanda. The purpose of this study is to investigate online collaborative learning can promote STEM education in HEIs aspects of the community of inquiry, namely, cognitive presence. Based on the existing literature, no research on online collaborative learning and cognitive presence in STEM education has been conducted in in the context of Rwanda. As a result, the findings of this study will be of interest to educators and students.

1.1 Contribution of the study

Current discoveries agree with Nsengimana et al. (2021) that students lack collaboration skills in online discussions. Also, Swan et al. (2009) and Redmond and Lock (2006) explain that online discussions could only be meaningful if course instructors organise and keep track of students and tasks. The present study reports that lecturers can work with group leaders to track defaulters in lessons and discussions.

This study contributes to the research body of knowledge and how practioners can adapt these findings for their online STEM education lessons. Firstly, the study engaged students to find out how they manage to study amidist several challenges while at the same time being successful. The study reports that students can train each other on basic ICT skills than only depending on external support from course instructors. Where students did not have access to WIFI, the use of tethering hot-spots (PTH) was a great substitute.

In addition, smartphones were used where students could not afford a laptop and hence equal opportunities offered by online STEM classes. This came as a solution to major challenge affecting online STEM learning, as reported that most HEIs lack adequate facilities, internet, technical knowledge and hardware (Bahati et al., 2019; Mukama & Andersson, 2008; Nsengimana et al., 2021; Rubagiza et al., 2020).

In a study conducted by Violaine (2019), it was reported that most students and lecturers have limited ICT skills to navigate e-learning systems and access affordable internet. However, during this study, we discovered that students collaboratively coached each other on essential ICT skills, something that allowed them to use simulations, animations, and YouTube independently. Students were actively engaged in STEM courses.

1.2 Purpose of the study

This study is guided by three objectives: firstly, the study explores how students learn STEM education through online small group discussions by examining the influence of cognitive and social presence factors. Secondly, the study investigates the relationship between cognitive and social presence in online discussions in STEM education. Finally, the study explores the challenges met by students during online STEM learning discussions and how they were solved.

1.3 The research questions

This study was geared to answer the following research questions (RQ):

RQ1: What are the students' perceptions on online STEM small group discussions?

RQ2: How is collaborative and interactive learning manifested in online STEM small group discussions among students?

RQ3: What is the relationship between social and cognitive presence supporting knowledge co-creation through online STEM small group discussions?

RQ4: What challenges and opportunities are experienced in online STEM small group discussions?

2 Literature review

2.1 Online collaborative learning

Keengwe and Kidd (2010) defines *online learning* as "a subset of distance education and embraces a wide set of technology applications and learning processes including computer-based learning, web-based learning, virtual classrooms, and digital collaborations" (p.533). On the other hand, *collaborative learning* is a shared intellectual effort among students or between teachers and students (Mukama, 2010; Nsabayezu et al., 2020). As such, virtual classrooms provide yet another learning environment for HEIs, especially STEM subjects that demand integration of ICT for a more interactive and motivating learning process.

With the advancement in digital technology, students in HEIs illustrate their preferences for online classes to face-to-face lessons citing their flexibility and ubiquitous nature (Keengwe & Kidd, 2010). Ogegbo and Adegoke (2021) found that online learning promotes students' interpersonal, exploration and creativity skills when well designed and executed. In addition, online computer-supported collaborative learning provides deep learning pedagogies and students build critical thinking skills through sharing, valuing, supporting, and discussion of ideas (Zhu Chang & Schellens, 2010). Students have vast up-to-date online sources of information that allow them to build knowledge from research findings on a topic under study.

2.2 STEM distance education in HEIs

Most universities have been adopting the use of virtual teaching models (VTM) in response to the Covid-19 pandemic for both distances and blended learning in HEIs (Verde & Valero, 2021). (Verde & Valero, 2021) During the COVID-19 pandemic, universities were using distance education modalities such as blended learning (hybrid learning and mirror rooms) and online guides in the classroom (Verde & Valero, 2021). Hybrid learning involves some students following the lesson in class and others following from home (Verde & Valero, 2021). Nevertheless, one of the greatest challenges to online STEM education is its limitation to conduct experiments. However, with the use of an online guide in the classroom, where students can access the campus, laboratory work has proved to work very well (Verde & Valero, 2021).

Similarly, Loughlin et al. (2019) discovered that the use of Math Skills Site (MSS) improved grades for STEM subjects in undergraduates' online learning. Some of the advantages of using the platform for online STEM education include quick and recursive feedback to students, easily accessible through smart devices including smartphones, user friendly and great collaboration (Violaine, 2019). It was found that Google classroom like other applications such as WhatsApp, and Canvas allows sharing of STEM multimedia with students from sites such as PhET and CK-12 Foundations, and YouTube which helps content retention, and motivation for autonomous learning (Nsabayezu et al., 2020; Violaine, 2019).

In Rwanda, several online learning platforms such as Sakai, Blackboard, Moodle, Google Classroom and Microsoft teams are used in HEIs STEM education to enhance both convectional learning and online learning (Nishimwe et al., 2022; Verde & Valero, 2021). However, some of these platforms do not have features for automated quizzes which can be supplemented through the use of more than one platform hence the need for HEIs to teach staff to be nerds in digital technologies (Ogegbo & Adegoke, 2021).

Allan et al. (2019) in the study *"Blended learning designs in STEM for higher education"* found several best practices that can be employed in online blended STEM education which include: course instructors to formulate objectives from which course activities and assessment should be derived from; Teaching and learning process to be more interactive with the integration of the technology, and use of e-assessment mainly.

2.3 Challenges in distance STEM education for HEIs

The outbreak of the COVID-19 pandemic led several universities to close their face-to-face learning and adopted online learning for continued teaching and learning. The decision to switch to online learning came with opportunities and challenges that both students and lecturers were not prepared to handle (Oliver, 2011; Syakdiyah et al., 2021; Verde & Valero, 2021; Wijenayaka & Iqbal, 2021). One of the challenges was how to teach science without access to the physical laboratory. In Indonesia, students at the Open University of Sri Lanka used Virtual Chemistry Lab spaces (VLCs) to fulfil the experimental activities for STEM subjects (Syakdiyah et al., 2021). At the end of the study, it was reported that VCLs promoted comprehension of abstract concepts and motivated students to learn (Wijenayaka & Iqbal, 2021).

3 Theoretical framework

3.1 Community of inquiry

Kanuka and Garrison (2017) define community of inquiry (CoI) as a collaborative educational approach that promotes deeper thinking in the learning process. Students work in small teams, support each other, and make reflections and inferences on shared ideas (Anderson et al., 2010). Misconceptions and unsubstantiated opinions from each student are brought to light through the co-creation of knowledge (Mukama, 2014). Students learn in their communities but not in isolation (Swan et al., 2009).

John Dewey wrote that knowledge inquiry is a social process and wrote that through collaboration, students tolerate each other and make sense of their learning (Swan et al., 2009). At the centre of CoI is the unity of a collaborative constructivist learning experience consistent with the legacy of John Dewey (Redmond & Lock, 2006). The CoI framework as the learning process is operated by the interaction of three presences: social, cognitive, and teaching presence (Swan et al., 2009). The three presences are discussed below:

3.1.1 Cognitive presence

Cognitive presence is the extent to which students build meaning through sustained reflection and teamwork in CoI (Anderson et al., 2001; Garrison, 2017). The focus of cognitive presence is higher-order thinking of students through metacognition. The presence has four factors triggering event, exploration, integration, and resolution that allow students to achieve in-depth knowledge construction (Anderson et al., 2001). The presence advances that the learning process occurs in stages where students move from one level to another. During a lesson, the facilitator triggers the students with an activity which they explore through the integration of their ideas and come up with a resolution.

3.1.2 Social presence

Further, while students are vetting ideas in small groups, there is high interaction and collaboration amongst them, and this is called social presence. Arnold and Ducate (2006) describe *social presence* as the capacity of students to identify themselves within a group and exchange ideas confidently. Social presence has three factors namely: affective expression open communication, and group cohesion (Garrison, 2017). The social presence instils affective connections, communication in a friendly manner and collaborative work amongst students.

3.1.3 Teaching presence

Although the social and cognitive presence dominates the learning process, the role of the teacher cannot be underestimated. Hence, the *Teaching presence* explains the design, facilitation, and steer the cognitive and social processes to realize meaningful learning outcomes (Garrison, 2009; Garrison et al., 2001). The teaching presence has three major factors: design and organization, facilitating discourse, and direct instruction (Shea et al., 2006). Therefore, the teaching presence sustains the learning process and addresses students' misconceptions and doubts (Swan et al., 2009).

4 Methodology

4.1 Research design and procedure

The mixed-method research design was used. A questionnaire and interviews guide helped to collect both quantitative and qualitative data (Creswell, 2017; Razaveih et al., 2015; Tashakkori & Creswell, 2007). The data for this study was collected from 88 STEM postgraduates from the University of Rwanda's College of Education in the Kayonza and Gasabo districts. The sample was purposefully chosen where only students with access to the Internet, and online learning were selected to participate in this study.

4.2 Research instruments

4.2.1 Questionnaire

Two questionnaires were adapted and developed from Anderson et al. (2010); Garrison (2017); Garrison et al. (2001) and Swan et al. (2009) based on the community of inquiry framework. Each questionnaire was divided into two parts: personal demographic information and a five-point Likert scale with 12 and 14 items, respectively. Google forms were used to code the questionnaires. Responses were directly recorded in Google forms and exported as spreadsheet file for data cleaning.

4.2.2 Interview

The interview guide with 14 items was designed by a team of research experts from the University of Rwanda, College of education based on a rigorous literature review. Oral interviews were conducted to collect data from the participants through WhatsApp and phone calls, and face-to-face. The data was later transcribed verbatim using Otter Pro software and analysed through content analysis.

4.3 Reliability and validity of instruments

Using IBM SPSS, the inter-item correlation, Cronbach's coefficient alpha of $\alpha=0.8$ and $\alpha=0.76$ were obtained for the pilot study and $\alpha = 0.701$ and $\alpha = 0.877$ at the implementation of the social and cognitive presence scale, respectively (Malizar & Fan, 2020). Factor analysis of the data *(social presence)* retained three factors (Eigenvalues: 4.618, 1.323, 1.137), accounting for 58.98% of the total variation. Similarly, for cognitive presence, three factors were retained (Eigenvalues: 5.619, 1.366, 1.158) and accounted for 58.16% of the total variance in the data, which was very significant (Masalimova et al., 2022). One item was not loaded into any component in the social presence questionnaire item. This item was removed and not used in the analysis.

4.4 Ethical consideration

The study did not include any students under the age of 18. The University of Rwanda granted preliminary permission to conduct research. The ethical consideration authorization issued by the Centre for Innovation and Research Unit,Unvesity of Rwanda, College of Education. Furthermore, all required ethical standards were strictly followed: no names were used on questionnaires, consent forms were signed by participants, and data was kept safe and used only for research purposes.

4.5 Data collection procedure

During this study, the researchers collected both qualitative and quantitative data in two phases. Phase 1 involved distributing the social and cognitive presence questionnaire to all participants through Google Forms. We disbursed 88 questionnaires, and all were returned within a period of one month. Phase 2 began amidst phase 1, where data was collected through oral interviews using a semi-structured interview guide. During this phase, 16 participants were interviewed.

5 Results

5.1 Participants demographic data

The sample comprised 26.1% females and 73.9% males. The majority of the participants had an age range of 26–30 (51.1%) and other were in the age range of 20–25 (3%); 31–35 (31.8%); and above 31 years old (13.6%). The participants' demographic data are presented in Table 1.

5.2 Student's perceptions and opinions about online STEM small group discussions

5.2.1 Social presence perceptions in online STEM small group discussions

We administered a five-point Likert scale questionnaire that had three categories: affective expression, open communication, and group cohesion. Mainly, the questions aimed at gathering information from students' experiences and perceptions of studying chemistry, biology, physics, and mathematics through online STEM small group discussions. The findings are presented in Table 2.

From these results, most participants showed that online STEM small group discussions were essential for their online studies. The high mean values *($M > 4.00$)* and standard deviation *($SD = < 1$)* were reported for each category and supported the observations ascribed by the researchers. The findings revealed that studying through online STEM small group discussions made a significant contribution towards student success. Furthermore, the researchers presented the information for each item using a clustered bar chart to understand participants perceptions better. The bar charts is plotted in Fig. 1 below.

5.2.2 Cognitive presence perspective in online STEM small group discussions

In order to explore more about cognitive presence perceptions a 14 items five-point Likert scale questionnaire with four categories: triggering, exploration, integration, and resolution was administered. The purpose was to discover how online STEM

Table 1 Participant demographic data

Demographic background	Frequency	Percentage
Gender		
Female	23	26.1
Male	65	73.9
Age range		
20–25	3	3.4
26–30	45	51.1
31–35	28	31.8
> 35	12	13.6
Major subject		
Biology	22	25.0
Chemistry	25	28.4
Physics	17	19.3
Mathematics	24	27.3
University of Rwanda		
Rukara campus	62	70.5
Remera campus	26	29.5
Cohort		
Master of Education Cohort 2	65	73.9
Master of Education Cohort 3	23	26.1
Profession		
High school teacher	49	55.7
Assistant lecturer	11	12.5
Unemployed	19	21.6
Other	9	10.2

Table 2 Mean and standard deviations for students' social perceptions in online STEM group discussions

Category $N = 88$	Overall mean	Standard deviation
AE-Affective expression (3 items)	4.60	0.751
OC-Open communication (4 items)	4.02	0.816
GC-Group cohesion (5 items)	4.32	0.670

Strongly disagree = 1, Disagree = 2, Undecide = 3, Agree = 4, Strongly agree = 5

small group discussions promoted creativity and higher-order thinking among students. Furthermore, we computed descriptive statistics for each category. The findings for the analysis are shown in Table 3.

The results showed that studying online STEM small group discussions enhanced critical thinking among the students through sharing and co-creating knowledge. The participants positively rated all the items, giving mean values for each category ($M > 4.00$). The standard deviations were less than 1 ($SD < 1.000$) for each category.

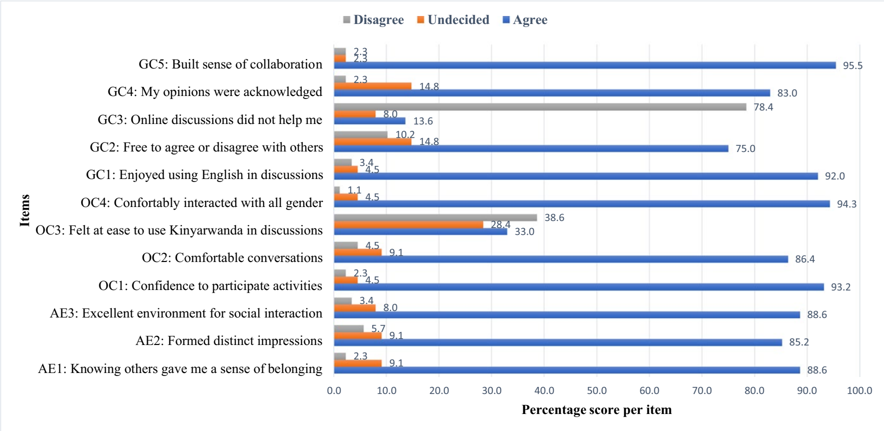

Fig. 1 Students' social perceptions in online STEM small group discussions

Table 3 Mean and standard deviation for cognitive perceptions in online STEM small group discussions

Cognitive perceptions *N* = *88*	Overall mean	Standard deviation
TRI-Triggering (3 items)	4.59	0.721
EXP-Exploration (4 items)	4.64	0.591
INT-Integration (3 items)	4.51	0.727
RES-Resolution (4 items)	4.41	0.839

Strongly disagree = 1, Disagree = 2, Undecided = 3, Agree = 4, Strongly agree = 5

The researchers visualized each item in a clustered bar chart so that details and patterns about students perceptions could be observed clearly from the data (Fig. 2).

Several participants reported that studying through online small group discussions enhanced higher-order thinking in STEM education. The student's ratings on the level of their cognitive performance in the major subject were visualized in a clustered bar chart (Fig. 3).

The results showed that online small group discussions had a positive cognitive impact in all STEM major STEM subjects. This explains why all students were successful while they studies online.

5.3 Collaborative and interactive online learning of STEM subjects

The study found that there was a high collaboration amongst students in their respective groups. For example, John illustrated: "I learned to work collaboratively with my groupmates at home. I improved my ICT skills through interaction with various ICT tools, which I would not have achieved when studying in a face-to-face classroom".

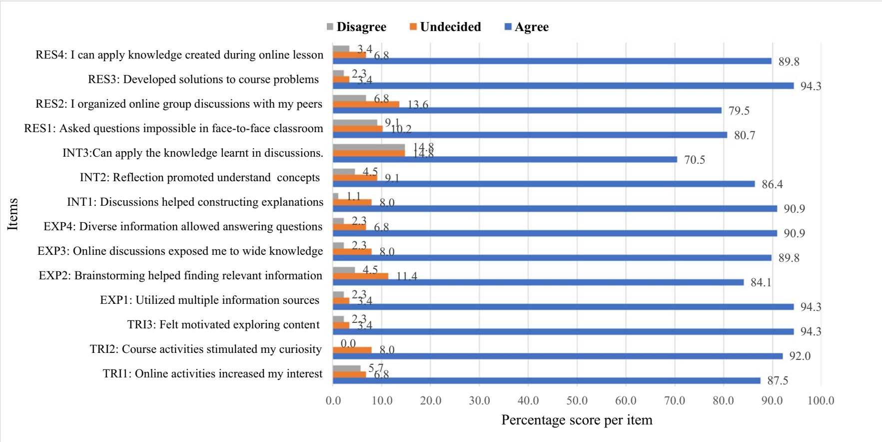

Fig. 2 Students' cognitive perceptions in online STEM small group discussions

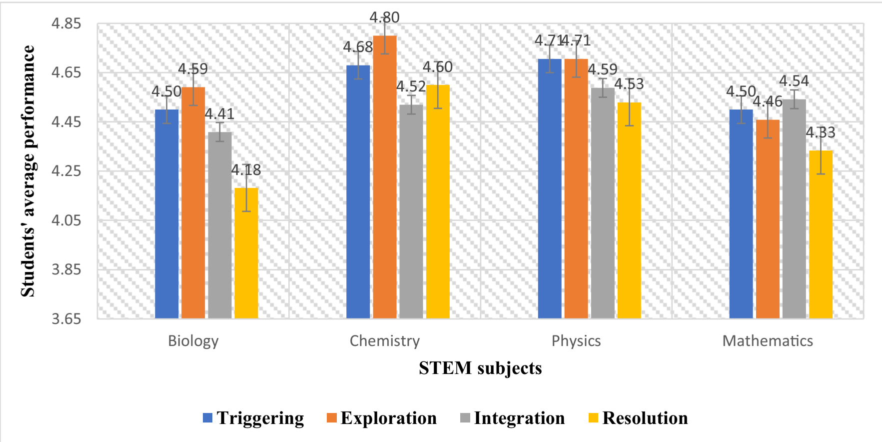

Fig. 3 Student's level of cognitive performance

Mary agreed with John and gave this example:

First, online STEM small group discussions were ubiquitous. We met anytime from anywhere. Second, we improved collaboration among classmates through interactions in small groups. Online small groups allowed me more time before answering a question and a case rarely practised in the traditional classroom.

Similarly, Evans illustrated that online STEM small group discussions allowed him to understand complex concepts in biology, such as plant systematics and molecular genetics. To better compare students' collaboration behaviour

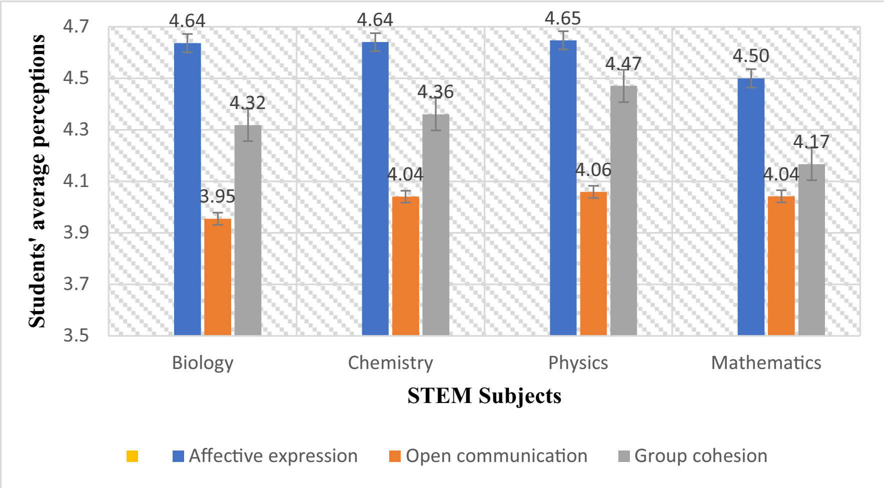

Fig. 4 Student's collaboration in STEM subjects

Table 4 Relationship between social and cognitive presence in online STEM small group discussions

Correlations *N*=*88*			Social presence	Cognitive presence
Spearman's rho	Social Presence	Correlation Coefficient	1.000	0.693**
		Sig. (2-tailed)		0.000
	Cognitive presence	Correlation Coefficient	0.693**	1.000
		Sig. (2-tailed)	0.000	

**. Correlation is significant at the 0.01 level (2-tailed)

during onlinre learning, a clustered bar chart for students' perceptions by major subject was plotted (Fig. 4).

5.4 Relationship between social and cognitive presence in online collaborative learning of STEM subjects

Spearman's correlation rank was computed using IBM SPSS, and the value obtained was statistically significant $r_s = 0.693, p < 0.01$. The value, $r_s = 0.693$ is a moderate positive correlation rank between social and cognitive presence factors (Table 4).

The results showed that there was a great affection and team work among the students in different major subjects. However, some students had problems with communication amomg the groupmates especially in biology classes.

5.5 Making online learning of STEM successful amidst challenges

5.5.1 Theme 1: Internet access and stability

Students voiced at length that they faced challenges with Internet connectivity and stability. The study found that most students used personal internet bundles on mobile phones because of no access to WiFi. "There was high traffic on service providers because all services went online in the country", William reported. Solange gave an example: "I experienced the challenge of the Internet connection. Sometimes, the Internet was too slow that I could not join a discussion". Thus, poor internet connection did not give equal study opportunities in online studies.

5.5.2 Theme 2: Access to stable power supply

Students were also affected by power outage during their online studies. Since most students used computers that work only when connected to electricity, intermittent power was a big challenge. James illustrated:

> *A significant challenge that I experienced was about power outage. My laptop was like a lamp; when the electricity went off, it shut down immediately. I could not attend the lessons or lessons equally with my classmates. The shortage of electricity affected my studies immensely.*

This means that when the power went off, some students were out of the online class, and those with good laptops continued to study; hence students had unequal online study opportunities.

5.5.3 Theme 3: Distractions from friends and family

Some students chose to use their smartphones for studies because they had more milliampere hours (mAh) relative to the phone size. Nevertheless, the study found that smartphones had their drawbacks—the major challenge was uncontrolled distractions from incoming calls and pop-up messages. Distractions from phones were difficult to control since one had to turn off the network which was not practical as the Internet connection went off automatically.

5.5.4 Theme 4: Lack of students' monitoring tools

Another common problem mentioned was about students joining online class without being there to participate in the lesson. Such conduct left a tremendous negative effect on the participation of group members as the same individuals who were active could dominate the lesson or discussion. The behaviour was typical in most discussions, as several respondents retaliated. Linda said: "I learned that some groupmates were inactive in most discussions. They were not participating, yet they had joined the class". Since the video cameras were off, there was no way of monitoring students' presence. The increased number of inactive groupmates reduced collaboration and interactions during group activities.

5.5.5 Theme 5: No access to laboratory work

Since face-to-face classes closed during the COVID-19 pandemic, students did not have access to laboratory experiments. Bongani reported: "We never conducted any practical work since we were studying from home". Participants reported challenges in understanding complex and abstract concepts without experimental support. This evidence confirmed the lack of practical aspects during students' online studies. Despite respondents' gratefulness for continued studies during the COVID-19 pandemic lockdown, these issues affected STEM learning. The students and course instructors were primarily unprepared before switching to online learning. However, some students reported that you managed to use free online virtual lab kits to conduct some experiments where possible. Virtual labs enhanced understanding of abstract concepts in chemistry, physics, mathematics, and biology. Some students explained that they used simulations, YouTube videos, animations, GeoGebra, Physics virtual labs, and Bio-interactive software as a remedy for lack of practicum.

6 Discussion

This study focuses on online collaborative learning and cognitive presence in STEM education. The following paragraph will discuss and relate the findings to the existing knowledge base. To a great degree, this study found that 97.5% of the students were satisfied that online STEM small group discussions were essential to their studies. Most respondents mentioned that the talks were beyond simple sharing and exchanging of ideas. Students' social interactions and collaboration were found to have a high mean, $M=4.60$ *(maximum)* and $M=4.02$ *(minimum)*, which is greater than 3.40, a lower limit interval as reported by Pimental (2010). The high mean value explains that most students liked to study through online small group discussions.

All the standard deviation (SD) values were greater than 0.5, with the highest $SD=0.75$ and the lowest $SD=0.670$ (Table 1), which express that most of the student responses were spread evenly above the mean. Students expressed commitment and excellent group collaboration while working (Fig. 2). However, students studying biology had the least freedom in their group discussions.

Although this study revealed high collaboration and more learning gains in each STEM subject (Fig. 4), other studies by Swan et al. (2009) reported that online learning discussions hardly promoted critical thinking. For example, Kanuka and Garrison (2017) assert that students simply exchange ideas without promoting deeper learning. However, this study indicated some difference in that the students from various STEM subjects gave highly positive feedback on the cognitive presence (Fig. 3). We observed mean values greater threshold of the upper limit equal to 4.20 *(strongly agree)*, a positive affirmation that critical thinking was enhanced in online collaborative learning in STEM.

The study demonstrates a moderate positive Spearman correlation rank between social and cognitive presence. The Spearman rank correlation coefficient was $r_s = 0.69, p<0.01$. Therefore, social, and cognitive factors support online STEM learning when conducted through small group discussions. Other studies by Anold and Ducate (2006), Kanuka and Garrison (2017) and Nsengimana et al. (2021) reported that when students study through online learning, advanced collaboration promotes cognitive skills. Nevertheless, the authors advised that teachers need to organize content, supervise, and clear students' misconceptions to achieve meaningful learning gains (Kanuka & Garrison, 2017; Nsengimana et al., 2021; Uwizeyimana, 2021).

Students managed to study through online discussions as group leaders and lecturers kept track records of activities ensuring timely completion. Kanuka and Garrison (2017) reported that creating a discourse in a virtual classroom that promotes higher-order thinking is a challenge. In that regard, we introduced online small group discussions in STEM learning. The results are add new knowledge to optimise online learning to enhance STEM education.

As reported in the results, several challenges were experienced during online STEM small group discussions. The most prominent one was about poor Internet connection. The situation gave unequal opportunities to study as students with poor Internet connection could not join the classes consistently. As this problem was common in Rwanda, studies in other countries reported similar issues, especially during the COVID-19 lockdown (Fan, 2020; Kolil et al., 2020; Nsengimana et al., 2021; Wijenayaka & Iqbal, 2021).

The study suggests the provision of stable and strong Internet in all universities and introduces subsidies for students' Internet bundles. Nevertheless, students used portable tethering hotspots to solve the problem of Internet challenges. Further, the lack of practical work was reported as serious challenge since students were studying remotely from home making it not possible to conduct any experiment. Instead, some students reported using free online virtual lab kits where possible. Previous studies had revealed that virtual labs can enhance understanding of abstract concepts in chemistry, physics, mathematics, and biology (Allan et al., 2019; Clark & Chamberlain, 2014; Tugirinshuti, 2021). Clark and Chamberlain (2014) found that simulations ignite critical and creative thinking amongst students. We also found that students used simulations, YouTube videos, animations, GeoGebra, Physics virtual labs, and Bio-interactive software as a remedy for lack of practicum. Most students became familiar with these tools through exposure.

Students from remote areas were significantly affected by blackouts that made it difficult to study. Electricity is essential to online learning as it powers computers, charging smartphones, and allowing the Internet access (Rubagiza et al., 2011). Students solved power outages through the use of smartphones to attend online group discussions. However, the present study revealed that some some students joined the discussions but never participated. Deserting discussions reduced collaboration amongst groupmates.

7 Implications for the study

Based on the current challenges facing STEM education in SSA and beyond, this study was sparked with interest to investigate how online collaboration can support the learning of STEM education in higher education. The findings of this study can help policymakers and instructional designers to enhance the quality of teaching, learning and assessment approaches in STEM courses. Since the study found that online STEM small group discussions were successful during COVID-19 lockdown, adapting this approach of teaching would be essential to address the current traditional practices in STEM education.

Students lack collaboration skills when studying through online virtual space (Nsengimana et al., 2021). Therefore, the current study results can assist educational managers, course instructors and trainers to re-think and re-strategize training programmes required for best teaching and learning through online small STEM group discussions. The current situation is that most schools online STEM studies are dominated by teacher-centered approaches regardless government initiatives and policies to promote learner-centered practices and ICT integration in HEIs (Rubagiza et al., 2020).

Third, education policy developers may use the findings of this study in pre-service and in-service teacher training in enhancing STEM education. Moreover, the results of this study may inspire Rwanda Basic Education Board (REB), the Ministry of Education (MINEDUC), and other stakeholders (USAID, UNICEF, World Vision) to support teachers through the provision of equipment and professional development training in online STEM collaborative learning and usage of virtual experiments to supplement lab hands-on practices.

8 Conclusion

This study explored online learning collaboration and cognitive presence through small group discussions by focussing on students' learning experiences in STEM subjects. Social presence, cognitive presence, and use of online small group discussions are considered as critical for students successful learning in STEM education. Students worked collaboratively and co-created knowledge through online small group activities. A moderate positive Spearman correlation rank between the social and cognitive presence was realized indicating a significant role played by the two factors in online STEM learning. Several challenges were reported in this study, including poor Internet connection, lack of laboratory work, limited ICT skills for both teachers and students, lack of monitoring of students' active participation, and sporadic power supply in remote areas. However, virtual labs were considered relevant in supplementing physical laboratories in online STEM learning.

9 Recommendations of the study

The study recommends more training for both students and lecturers. Efforts should be put in place to train lecturers and assistant lecturers in leveraging ICT and software teach STEM education through online small group collaboration. To this end, the researchers recommend the expansion of Internet coverage on campuses to support online learning and blended lessons. With wide coverage of stable Internet, students would utilize online social networks platforms for their online STEM studies.

The study strongly recommends the integration of ICT and use of interactive multimedia such as Bio-interactive, Physics Education Technology (PhET) interactive simulations in STEM to supplement lab experiments since these tools can support cognitive and affective domain in the learning process. With the advancement of technology in the 21^{st} century, teaching and learning of abstract content can be done with ease if course instructors maximizes the use of these interactive multimedia. Additionally, these tools can help educational institutions to solve the problem of expensive and inadequate laboratory materials by adopting the use of virtual laboratories especially in online remote classes.

Course instructors, trainers and lecturers are recommended to use online STEM small group discussions to maximize attainment of outcomes of learning.

The focus of this study was online STEM small group discussions and the aspect of gender was not explored. Thus, this study further recommends that more research could be conducted to explore the impact of using online STEM small groups discussions with a focus on gender gender aspects. The researchers suggest that more studies with randomized sampling to examine the effect of gender on active engagement in online STEM small group discussions in STEM courses.

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Data availability Data supporting this study will be made available from the corresponding authors upon reasonable request.

Declarations

Ethical statement The Directorate of Research and Innovation at the University of Rwanda-College of Education has reviewed and confirmed that this research adhered to ethical standards and principles. The document number is **Ref:03/DR1-CE/026/EN/g/2021**.

Consent statement Participating students gave informed consent to be involved in the study.

Conflict of interest statement None.

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Authors and Affiliations

Leonard Nungu[1] · **Evode Mukama**[1,2] · **Ezechiel Nsabayezu**[1]

Leonard Nungu
nunguleonardisaac@gmail.com

Evode Mukama
emukama@col.org

Ezechiel Nsabayezu
ezechielnsabayezu109@gmail.com

1 African Centre of Excellence for Innovative in Teaching and Learning Mathematics and Sciences (ACEITLMS), University of Rwanda-College of Education (UR-CE), Rukara Campus, Kigali, Rwanda

2 Commonwealth of Learning, Vancouver, BC, Canada