

Developing and testing a Framework for Learning Online Collaborative Creativity (FLOCC) in medical education: Cross-Sectional Study

Shairah Radzi, Joo Seng Tan, Preman Rajalingam, Jennifer Cleland, Sreenivasulu Reddy Mogali

Submitted to: JMIR Formative Research
on: July 18, 2023

Disclaimer: © The authors. All rights reserved. This is a privileged document currently under peer-review/community review. Authors have provided JMIR Publications with an exclusive license to publish this preprint on its website for review purposes only. While the final peer-reviewed paper may be licensed under a CC BY license on publication, at this stage authors and publisher expressly prohibit redistribution of this draft paper other than for review purposes.

Table of Contents

Original Manuscript..... 5

Supplementary Files..... 41

0..... 41

Figures 42

Figure 1..... 43

Figure 2..... 44

Figure 3..... 45

Multimedia Appendixes 46

Multimedia Appendix 1..... 47

Multimedia Appendix 2..... 47

Multimedia Appendix 3..... 47

Multimedia Appendix 4..... 47

Multimedia Appendix 5..... 47

Multimedia Appendix 6..... 47

Developing and testing a Framework for Learning Online Collaborative Creativity (FLOCC) in medical education: Cross-Sectional Study

Shairah Radzi¹ PhD; Joo Seng Tan² PhD; Preman Rajalingam³ PhD; Jennifer Cleland³ PhD; Sreenivasulu Reddy Mogali³ PhD

¹ Lee Kong Chian School of Medicine, Nanyang Technological University Singapore Singapore SG

² Nanyang Business School, Nanyang Technological University Singapore Singapore SG

³ Lee Kong Chian School of Medicine, Nanyang Technological University Singapore Singapore SG

Corresponding Author:

Sreenivasulu Reddy Mogali PhD

Lee Kong Chian School of Medicine, Nanyang Technological University Singapore
11 Mandalay road
Singapore
SG

Abstract

Background: Collaborative Creativity (CC) is a social process of generating creative and innovative solutions to real-world problems through the collective effort and interaction of a group of people. By taking this approach, medical students can cultivate the abilities and mindset required to be creative thinkers, develop teamwork and interdisciplinary learning, complex problem-solving, and provide outstanding patient care. However, medical students ranked low on creativity, sparked by existing pedagogical approaches that focus more on knowledge outcomes, and the professional challenges for doctors and healthcare professionals have become more complex in an ever-evolving healthcare ecosystem requiring collaborative creativity.

Objective: This study objective was to develop, test, and evaluate the acceptability of a new framework for learning online Collaborative Creativity (FLOCC).

Methods: FLOCC builds upon the established pedagogical approaches of rapid Design Thinking, Team-Based Learning (TBL) and Problem-Based Learning (PBL) and is scaffolded by four individual asynchronous (Empathy Map, Frame Your Challenge, Turning Insights into How Might We Questions, and Individual Brainstorming) and five collaborative synchronous activities (Bundle Ideas, List Constraints, Final Idea, Prototyping and Blind Testing). Eighty-five medical students took part in two feasibility studies (study 1, n=44; study 2, n=41) differentiated by two problems (healthcare and engineering sustainability issues). Learner acceptability was measured using a 31-item survey (using 7-point Likert scale) consisting of four factors (Distributed Creativity, Synergistic Social Collaboration, Time Regulation and Achievement, and Self and Emotions) and three free text questions.

Results: Most students were positive about FLOCC, scoring higher mean percentages of 'Agree' in the first two factors (92% and 88%), followed by the latter two factors (80% and 70%); indicating high level of acceptability. Only Time Regulation and Achievement was statistically significant ($P < 0.01$) between means of studies 1 and 2. Effect size was larger in Self and Emotions and Time Regulation and Achievement ($\eta^2 = 0.34$ and 0.72 , respectively), than Synergistic Social Collaboration and Distributed Creativity (Cohen's $d = 0.01$ for both).

Conclusions: With effective time management, the FLOCC has potential as a tool or framework for nurturing collaborative creativity in medical students. Medical schools could provide the opportunity and environment for medical students to be creative thinkers; therefore, creativity approaches could be integrated into the curriculum to possibly foster the culture of creativity for breakthrough solutions by future doctors of the 21st century.

(JMIR Preprints 18/07/2023:50912)

DOI: <https://doi.org/10.2196/preprints.50912>

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain visible to all users.

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <http://www.jmir.org/>

No. Please do not make my accepted manuscript PDF available to anyone.



Original Manuscript

Original Article

Developing and testing a Framework for Learning Online Collaborative Creativity (FLOCC) in medical education: Cross-Sectional Study

Shairah Radzi¹, Tan Joo Seng², Preman Rajalingam¹, Jennifer Cleland¹, Sreenivasulu Reddy Mogali^{1*}

¹ Lee Kong Chian School of Medicine, Nanyang Technological University Singapore, Singapore

² Nanyang Business School, Nanyang Technological University Singapore, Singapore

*Correspondence to:

Dr. Sreenivasulu Reddy Mogali

Lee Kong Chian School of Medicine

Nanyang Technological University Singapore

11 Mandalay Road, Nanyang Technological University Singapore,

Singapore 308232

E-mail: sreenivasulu.reddy@ntu.edu.sg

Abstract

Background: Collaborative Creativity (CC) is a social process of generating creative and innovative solutions to real-world problems through collective effort and interaction. By engaging in this process, medical students can develop abilities and mindset for creative thinking, teamwork, interdisciplinary learning, complex problem-solving, and enhanced patient care. However, medical students have demonstrated limited creativity, constrained by existing pedagogical approaches that predominantly emphasize knowledge outcomes. The increasing complexity of healthcare challenges necessitates a pedagogical framework for medical students to foster collaborative creativity in a rapidly evolving professional environment.

Objective: The objective of this study was to develop, test, and evaluate a new Framework for Learning Online Collaborative Creativity (FLOCC).

Methods: FLOCC builds on established pedagogical approaches such as Design Thinking and integrates sociocultural learning methods (Team-Based Learning (TBL) and Problem-Based Learning (PBL)). It includes four individual asynchronous activities (Empathy Map, Frame Your Challenge, Turning Insights into How Might We Questions, and Individual Brainstorming) and five collaborative synchronous activities (Bundle Ideas, List Constraints, Final Idea, Prototyping and Blind Testing). In this cross-sectional study, eighty-five undergraduate medical students participated in two separate studies (study 1, n=44; study 2, n=41) involving healthcare and engineering sustainability problems. Learner acceptability was measured using a 31-item survey (using 7-point Likert scale) consisting of four factors (Distributed Creativity, Synergistic Social Collaboration, Time Regulation and Achievement, and Self and Emotions) and three free text questions. Free-text comments were subjected to the inductive thematic analysis.

Results: Most students were positive about FLOCC, with Distributed Creativity and Synergistic

Social Collaboration factors receiving the highest mean percentages of 'Agree' (92% and 88% respectively). These were followed by Time Regulation and Achievement factor (80%) and the Self and Emotions factor (70%). Only Time Regulation and Achievement was statistically significant ($P < 0.01$) between means of studies 1 and 2. Thematic analysis revealed four themes such as learning experiences, collaborative responsibilities, perceived skill development, and technical challenges.

Conclusion: With effective time management, FLOCC shows potential as a framework for nurturing collaborative creativity in medical students. Medical schools could provide the opportunity and environment that supports creative thinking; therefore, creativity-focused approaches could be integrated into the curriculum to encourage a culture of creativity for breakthrough solutions by future doctors.

Keywords: collaborative creativity, design thinking, medical education, social cultural learning, collaborative learning.

Background

Many jobs require graduates to engage in collaboration with other professionals, exhibit creativity in solving difficult problems and manage uncertainties in their careers. In medicine, doctors must work in teams to effectively manage patient care. They are also increasingly expected to work together to solve real-life healthcare challenges such as managing complex patient problems in a milieu where specialized medical services and manpower are scarce [1].

Over a century has passed since Flexner's influential report [2], and medical education has undeniably experienced substantial changes, however, traditional medical education fail to cultivate the necessary creativity to handle difficult, ill-defined, or "impossible-to-solve" issues or problems which require multiple stakeholders to collaborate and innovate [3]. By default, pedagogical approaches in medical education tend to emphasize knowledge acquisition, retention and problem-solving within a limited context [4]. In general, learning in medical school includes two types of knowledge: factual and procedural knowledge. Mann comprehensive analysis [5] underscores that socio-cultural learning theories, rooted in the work of Vygotsky [6], present a valuable theoretical framework for shaping future medical education.

Significant ramifications arise from major modifications in medical education such as changes in our ways of knowing, changes in the discourse of medical education, changes in our view of medical education, which ultimately impacts the practice of medicine. The recent study by Fernández-Rodríguez found that the traditional teaching and assessment are still overused to the detriment of other teaching methods in medical education [7]. These methods typically measure the knowledge via written examinations focusing individual cognitive knowledge [8], not collaboration and creativity capabilities.

According to Guilford, creativity is the ability and skill to create novel and innovative things [9]. In

Stein (1953) classical paper, standard definition of creativity referred as “creative work is a novel work that is accepted as tenable or useful or satisfying by a group in some point in time” [10]. There is no single, agreed-upon definition of creativity due to its multidimensional nature [11]. But most agree that it requires the following four skills: the capacity for idea production (or "fluency"), attention to detail (or "elaboration"), originality (or "freshness"), and versatility (or "flexibility") [12-14]. Kampylis and Valtanen conducted an analysis of the 42 explicit definitions of creativity [15]. Walia conceptualizes creativity as an ongoing act, irrespective of whether it results in a tangible creation [16].

In the context of education, collaborative learning is broadly defined as students working in groups of two or more sharing responsibility for tasks and/or products [17]. The fundamental factors for collaborative learning include Respectful behavior, constructive feedback, a shared objective, acceptance of roles, engagement, and self-awareness [18]. The collaboration has been shown to foster the critical thinking by allowing students to debate ideas, engaging higher-order cognitive reasoning [19]. This highlights the importance of incorporating creativity and collaboration in medical curricula to address the problems in rapidly evolving health care system [20]. It also teaches students to view mistakes as opportunities for improvement when they are pushed to be creative [20].

Collaborative Creativity

Miell and Littleton (2004, pp. 1-2) describe Collaborative Creativity as a social process that promotes the creative process in the form of relationships in completing group tasks [21]. The research on collaborative creativity in medical education research is very limited, even though medical practices require teamwork and creative problem solving [22]. The recent systematic review differentiates collaborative creativity (explicitly generating new ideas) from creative collaboration (focusing on how people work together, with creativity embedded) [12]. Hill et al. (2014) emphasize that innovation is not about solo genius [23] but is about the collective genius of collaborative

problem solving, requiring three capabilities: creative abrasion (idea generation via debate), creative agility (rapid experimentation), and creative resolution (integrative decision-making) [29].

Several other factors impact Collaborative Creativity, such as diversity of the team [24, 25]; team interaction behaviors and conflict resolution [24, 25]; task independence [26, 27]; and the virtual or physical work space [28]. Online learning increased during the COVID-19 pandemic, demonstrating how digital platforms offer real-time co-creation and interaction. The information and communication technologies (ICT) facilitates collaborative content creation through social contact among users and encourages user-to-user communication and co-creation [29]. Gundogdu and Merc (2022) review found that web-based and cloud technologies, simulations, and smart tools help support technology-mediated collaborative creativity [30]. It was found that student performance is comparable to in-person learning [31]. In terms of questioning behavior and project performance, the online group performed better than the face-to-face group on collaborative tasks [32]. In the creative fields such as design and art, frameworks using technology to promote collaborative creativity have become more common [33-35]. As higher education continues to expand online, medical programs must adapt to remain globally competitive and foster 21st-century competencies, including collective problem-solving, communication, and creativity [34].

While notable progress has been made in medical technology, education still lacks sufficient emphasis on creativity, which is crucial for problem-solving in the medical field [22]. Medical education often utilizes instructional methods such as traditional lecture-based, problem-based learning (PBL) and team-based learning (TBL). While the evidence indicates that structure of the PBL and TBL linked to learning enhancement, evidence of systematic attempts to foster collaborative creativity remains limited [36-39]. Some researchers explored other creative methods in medical education such as brainstorming [40], concept maps [41], and storytelling [42] but collaborative creativity still receives minimal attention. This is a critical gap in the literature, since

Collaborative Creativity (or lack thereof) can impact the medical professional-patient relationship [43], job engagement, satisfaction, and performance [44], and patient safety [45]. Thus, a need exists to create strategies and frameworks that incorporate the collaborative creativity into medical education especially by leveraging online learning technologies to equip future medical professionals for the multifaced realities of evolving healthcare.

Therefore, our aim was to develop and test a novel design-based thinking framework for online collaborative creativity (FLOCC). Our research questions were:

1. What existing pedagogical principles could be utilized to create a novel FLOCC for fostering collaborative creativity skills in medical students?
2. How could this FLOCC be operationalized?
3. What are students' perceptions and attitudes towards the FLOCC?

Methods

This study reports the development and operationalization of a new framework for learning online collaborative creativity (FLOCC) and its preliminary evaluation. The first stage in this process was to consider the conceptual underpinnings and structure of the FLOCC explicitly. The concepts underpinning FLOCC are depicted in Figure 1 and outlined below.

.... Figure 1 about here

Conceptual Underpinnings of FLOCC

FLOCC integrates the principles of rapid design thinking (RDT) with a socio-cultural learning approach, encompassing elements of Team-Based Learning (TBL) and Problem-Based Learning (PBL). In both TBL and PBL learning takes place through interaction, negotiation, and collaboration

in solving clinical problems. Hence, our goal is to identify the convergences of these methodologies within the framework of a collaborative, socio-cultural learning grounded in Vygotsky's socio-cultural paradigm [6]. Dolmans et al. (2015) highlights how combining TBL and PBL could synergistically enhance problem solving skills, RDT framework further orients towards innovation and iterative solution creation. The current evidence supports the efficacy of TBL in enhancing the academic performance among the lower-performing medical students [46], while it may be greater demanding [36, 38]. Conversely, PBL, has been linked to the development of a broader range of skills such as interpersonal skills, self-directed learning, planning and analytical skills [39]. However, some researchers have shown no difference between problem-based learning and traditional learning in medical education [47] and caution that PBL effectiveness depends on frequent feedback [48].

Design thinking, defined as "a future-oriented method/process/toolbox/mindset" to promote collaborative and creative learning, adopts a human-centered problem-solving approach [49]. While design thinking has seen growing presence in STEM education [50] but its application in medical education remains very limited. A recent review identified only seven pertinent studies, three involving medical students [49, 51]. However, while limited in number, these studies and recent opinion pieces suggest design thinking may be an appropriate framework to foster student/patient/practitioner outcomes such as self-efficacy, learning experiences, and academic development [52, 53]. Furthermore, using design thinking opens up a new area for investigation to help educators understand, measure, and assess the experiences of students to promote creativity [54], to create a new product and/or to establish a way of thinking about problems via the development of a novel product [49].

Common characteristics shared by socio-cultural learning methods and RDT include goal orientation, team activity, brainstorming, and problem-solving. From these perspectives, learning is

impacted at individual and collaborative levels through active engagement and shared goals [55]; building on knowledge through social interaction, constructive arguments and cooperation with others rather than passive learning [56]. From the social constructivist perspective, learning is more efficient in a group setting as knowledge develops as a result of social interaction and language use [57]; hence, students demonstrate more motivation and self-confidence in collaborative learning environments [58]. Through team conversations, students become more adept at identifying problems and pursuing solutions, leading to the process of problem-solving [59]. When individuals are accountable for building their own knowledge and communicating successfully with others, these activities can favorably influence collaborative creativity [60].

In alignment with the socio-cultural learning paradigm and echoing the integrative perspective of Dolmans et al.(2015) [61], we propose combining TBL, PBL and Design thinking (RDT) within FLOCC , harnessing the strengths of each method: TBL's accountability and readiness assurance process [62], PBL's "ill-structured" problem as a stimulus of thinking [63], and RDT's creative process and quick prototyping [64].

Thus, FLOCC can be viewed as a hybrid pedagogical framework that combines key perspectives from PBL, TBL, and design thinking to tackle complex medical problems with collaborative creativity skills.

Structure of FLOCC

Process-based frameworks like FLOCC should capture the creative process and promote 'mindful idea generation' in a sequential manner [65]. For this, four of the investigators (SR, TJS, PR and SRM), all experienced educators in TBL and PBL, adapted the three phases of FLOCC (Inspiration, Ideation and Implementation) from the Rapid Design Thinking (RDT) model, an accelerated version of the Stanford's design thinking (DT) model, known as a 'people-oriented problem-solving method'

[66]. Through iterative discussions and consensus, RDT was chosen as it was especially useful in rapidly changing environments like Covid-19 whilst offering learners similar features to DT [64]. FLOCC includes four individual asynchronous activities (Empathy Map, Frame Your Challenge, Turning Insights into How Might We Questions, and Individual Brainstorming) and five collaborative synchronous activities (Bundle Ideas, List Constraints, Final Idea, Prototyping and Blind Testing). These activities are incorporated into the three distinct phases of FLOCC, as explained in detail below:

Inspiration

Inspiration refers to defining a problem that can inspire opportunities for creative solution [64]. This phase requires understanding, observing, or listening to people with unmet needs. This means students would require both communication skills and some domain knowledge [67] to empathize with end users' unmet needs and be open to multiple possibilities. Problems here serve as the creativity trigger [68], akin to PBL, and students may benefit from preparatory materials to support the thought process, similar to Pre-TBL preparation. Inspiration uses two individual learning scaffolds such as Empathy map (I1) and Frame your challenge (I2) [69]. These activities help individual learners systematically write down their insights, analyze stakeholders, contexts and think about potential solutions, forming a basis for ideas generation.

Ideation

The ideation phase reinforces observations and experiences recorded during inspiration via the generation of ideas and identification of potential solutions [67, 70]. This phase is a dual-purpose scaffold to support individual learners and teams because it requires generating novel ideas or solutions about a topic at an individual level first, then team level. Here, students work individually

using the “how might we question” (I3 – turning their insights into opportunities for design via divergent thinking) and “Individual Brainstorming (I4 - to write as many ideas as possible based on I3). Then students do team brainstorming where they combine and filter individual ideas through the team processes such as “bundle ideas” (T1) “list constraints” (T2) and final idea, (T3) and culminating in “prototyping” (T4). Rapid prototyping—a hallmark of design thinking encourages teams to translate their insights into tangible artifacts or solutions [71].

Implementation

Implementation refers to the process where designers test a solution by converting it into a working product and testing its feasibility and market value. This requires problem-solving which can happen via collaboration and mutual feedback [72]. Based on this, the last team-learning scaffold i.e., “blind testing” (T5) created where teams assess the usability and feasibility of each other’s prototypes and provide feedback to refine them iteratively.

Figure 2 depicts the stages of FLOCC and how it maps onto the characteristics of PBL, TBL and RDT.

.... **Figure 2 about here**

Operationalising FLOCC

Following conceptualization, our next step was to operationalize FLOCC. The entire study was conducted online due to the COVID-19 pandemic. For operationalizing self-study in individual scaffolds, we provided a project website (Google Sites, Enterprise Standard, Google LLC, USA) hosting explanatory videos about FLOCC and a downloadable Excel spreadsheet for collecting responses (Supplementary Material 2) of I1 to I4 individual scaffolds. The individual scaffolds were assigned in an asynchronous online learning format. An overview of the project website and a sample

of individual Excel spreadsheets can be found in Supplementary Materials 1 and 2, respectively.

For team scaffolds (T1 to T4), Google Sheets (Enterprise Standard, Google LLC, USA) was used to collect team responses simultaneously and in real-time. A sample of the Team Google Sheets can be found in supplementary material 4. Additionally, a YouTube video on prototyping was also included [73].

The overall flow of FLOCC is captured in Figure 3.

.... **Figure 3 about here**

Evaluation of FLOCC

Ethics approval and consent to participate

This study was conducted according to the Declaration of Helsinki, approved by Nanyang Technological University (NTU) Institutional Review Board (IRB 2020-08-036) prior to its commencement; and students who participated in this study provided full informed consent. The participants were recruited through class announcements and email correspondence. Participation in the study is voluntary, and it is conducted as an extracurricular activity outside of regular school hours. To show their appreciation for taking part in the study, each participant received SGD 50. The study data are anonymous, and no images of the manuscript or supplementary material identify individual participants.

Study participants

We carried out an cross-sectional study to evaluate FLOCC using mixed methods to assess student

acceptability of FLOCC. Ayala and Elder (2011) define acceptability as "how well an intervention will be received by the target population" [74]. The participants were undergraduate medical students of Lee Kong Chian School of Medicine (LKC Medicine), Nanyang Technological University Singapore. The TBL is the main pedagogy at LKC Medicine, so some TBL elements in FLOCC might feel familiar to the students. We invited the first three years of MBBS students for better representation and to reduce the possibility of selection bias. We also asked them to complete the survey fully to ensure that the data is complete and validate the survey results. The evaluation conducted at two points with two different creativity triggers: study 1 representing the medical (How might we create sustainable healthcare practices to cater to the growing population?) and study 2 related to engineering, (How might we create sustainable engineering practices to cater to the growing population?).

Factors to measure collaborative creativity

Mavri et al. (2020) developed the 'Assessment Scale for Creative Collaboration (ASCC) to measure social collaborative creativity in blended learning settings [75]. The ASCC measures three factors: 1. Synergistic Social Collaboration (communication and interaction), 2. Distributed Creativity (divergent thinking and collective innovation), 3. Time Regulation and Achievement (time management for shared goals).

We adapted 21 items from the ASCC for the present study, to quantify the acceptability of the students towards online collaborative creativity. We added three new items to Synergistic Social Collaboration and two new items to Time Regulation and Achievement to better reflect the role of facilitation as a potentially motivating factor towards collaborative creativity, and the level of engagement of students in both individual and team activities used in the study (see Supplementary Material 3). Finally, in response to literature which indicates that a learner's emotional state may also influence collaborative creativity [76-78], we also created a new fourth factor called Self and

Emotions, which considered five items related to confidence, pride, worry and self-consciousness. In summary, there were a total of thirty-one items across the four factors, all in the format of a 7-point Likert scale (1 = Strongly Disagree to 7 = Strongly Agree). Three free-text questions were also given to collect students' opinions about the strengths, weaknesses, and suggestions to improve the FLOCC.

Delivery

Following informed consent, participants received creativity trigger 1 via email. Students were given 1.5 weeks to complete the individual scaffolds (I1 to I4) before engaging in synchronous online team assignments and discussions held in Microsoft Teams for the team activities of FLOCC. The introduction of the study was conducted by SRM and synchronous part of FLOCC was facilitated by PR who explained the ground rules in the main room (e.g., respecting the views of others, do not interrupt), the design thinking processes and how to use the scaffolds for each team activity. Another investigator (SR) was also present to support the digital collaborative platforms (Google Workspace and Microsoft Teams) used in the study.

After this, teams ($n \leq 7$ per team) were put into breakout rooms to introduce themselves (Ice breaker: 7 minutes), then brought back to the main room for an explanation of each team events. Teams were given weblinks to Google Sheets to complete T1: Bundle Ideas in 30 minutes. The toggling between the main to breakout rooms were repeated for the rest of the steps in the following order - T2 and T3: List Constraints and Final Idea (30 minutes), and T4: Prototyping (30 minutes). A team representative was required to talk about their digital products for 5 minutes using the Prototyping section of the Google Sheets. Then, in the Implementation phase, the final team activity Blind Testing was carried out (10 minutes). Here, students were asked to complete T5: Blind Testing in Google Sheets by answering the free text questions and rating the feasibility, viability, and durability of the other team's prototype, as explained in the Implementation phase. After study 1,

participants received a second trigger (sustainability in engineering) for study 2, following similar procedures. A debrief closed each session. The examples of team's digital products and solutions to triggers 1 and 2 can be found in supplemental material 5 and 6, respectively.

Data collection

At the end of each study, the survey (7-point Likert scale items) in Google Forms measured the students' perceptions of the FLOCC. Students were given 20 minutes to complete the survey.

Analysis

Likert-scale questions were analysed using SPSS (version 28, IBM Corp, NY, USA). Cronbach's alpha was calculated to determine the internal consistency of the survey items within each of the four factors (Self and Emotions, Synergistic Social Collaboration, Distributed Creativity, and Time Regulation and Achievement). Alpha value of more than 0.7 was considered satisfactory [78].

After determining the internal consistency of items, the mean and standard deviations, and the percentages of agree, neutral and disagree were consolidated from the 7-point Likert scale at the team, study, and overall cohort levels. This was followed by a Shapiro Wilk and Levene's test to determine normality and homogeneity. Data that were normally distributed and equally varied were subjected to an independent samples t-test and Cohen's d to determine the statistical significance of means and magnitude (variability) of mean differences [79]. If not normally distributed, data were subjected to the homogeneity of variance for the eligibility of the Mann Whitney *U*-test for statistical calculations based on the mean ranks instead [79]. After that, the eta squared effect size (η^2) was calculated to determine the magnitude (variability) of the mean ranks. If eta squared values were found to be negative i.e., mean scores of study 2 were larger than study 1, they were reported as absolute values for simplicity purposes. A $P < 0.05$ was considered statistically significant.

The qualitative free-text comments of study 1 were subjected to thematic analysis to gain insights into the FLOCC. The comments selected from the first study were primarily chosen based on factors such as the presence of significant and representative qualitative data, as well as their suitability for thorough analysis. The analysis was done using Nvivo (version 12, QSR International, Victoria, Australia) via inductive coding by two coders (SR from the research team and RC external to the study) [80, 81]. Any disagreements were resolved by a third coder (SRM).

Ethics approval

This study was approved by Nanyang Technological University Institutional Review Board (IRB 2020-08-036). All participants provided written informed consent before taking part.

Results

Demographics

Eighty-five Years 1-3 MBBS students (38 males; 47 females, aged 18-22) participated in two studies. Forty-four students participated in Study 1 (21 males, 23 females, aged 18-22), and 41 in Study 2 (17 males, 24 females, aged 19-22). The mean age in each study and the overall sample population ($n=85$) were similar (20.3 ± 0.9). All participants completed the survey.

Internal consistency of the questionnaire

Initial Cronbach's alpha for the factors Self and Emotions, Synergistic Social Collaboration, Distributed Creativity and Time Regulation and Achievement were 0.42, 0.88, 0.63 and 0.66 respectively. Items 2 (I feel self-conscious when I present my ideas to other people), 21 (We felt pressured to create something original), and 27 (We felt pressured to complete the activity on time) were discarded as their contribution lowered the respective factors Cronbach's alpha <0.70 [82]. Upon their removal, the Cronbach alpha values improved [83], resulting in a refined Twenty-eight

item instrument (Supplementary Material 3) with alpha values were 0.75 (Self and Emotions), 0.88 (Synergistic Social Collaboration), 0.75 (Distributed Creativity) and 0.74 (Time Regulation and Achievement).

Students' perceptions on FLOCC

Overall, the study findings (based on refined 28-item instrument) indicated that most students in the total sample ($n=85$) had positive views of FLOCC across all four factors (70 – 92%) (Table 1). Distributed Creativity (5.97 ± 0.14) and Synergistic Social Collaboration (5.68 ± 0.2) displayed higher mean scores, followed by Time Regulation and Achievement (5.44 ± 0.22) and Self and Emotions (5 ± 0.3). These trends were consistent in both studies (study 1, $n=44$; study 2, $n=41$), where Distributed Creativity and Synergistic Social Collaboration emerged with higher mean scores than the other two factors (Table 2).

Table 1: Summary of percentage frequency results segregated by team, study, and overall sample population levels ($n=85$) for each of the four factors (Self and Emotions, Synergistic Social Collaboration, Distributed Creativity, and Time Regulation and Achievement).

		Frequency Scores (%)					
		Study 1 ($n=44$)			Study 2 ($n=41$)		
		Teams 1 to 8			Teams 1 to 7		
Factors	Levels	Agree	Neutral	Disagree	Agree	Neutral	Disagree
Self and Emotions	Team	66.67	8.33	25	75	10.71	14.29
		56.25	12.50	31.25	67.86	14.29	17.86
		78.57	10.71	10.71	79.17	0	20.83
		67.86	21.43	10.71	70	15	15
		54.17	8.33	37.50	65	15	20
		68.75	12.50	18.75	80	20	0

		46.43	7.14	46.43	83.33	4.17	12.50
		79.17	8.33	12.50			
	Study Overall	64.77	11.36	23.86	74.39	10.98	14.63
	Population Overall	Agree: 69.41; Neutral: 11.18; Disagree: 19.41					
Synergistic Social Collaboration	Team	91.67	5.56	2.78	94.05	4.76	1.19
		97.92	2.08	0	90.48	9.52	0
		83.33	4.76	11.90	84.72	9.72	5.56
		91.67	8.33	0	90	6.67	3.33
		76.39	13.89	9.72	90	6.67	3.33
		89.58	8.33	2.08	90	3.33	6.67
		84.52	8.33	7.14	77.78	12.50	9.72
		94.44	2.78	2.78			
	Study Overall	87.88	7.01	5.11	88.21	7.72	4.07
	Population Overall	Agree: 88.04; Neutral: 7.35; Disagree: 4.61					
Distributed Creativity	Team	94.44	5.56	0	100	0	0
		95.83	4.17	0	100	0	0
		88.10	9.52	2.38	94.44	5.56	0
		92.86	7.14	0	93.33	6.67	0
		94.44	2.78	2.78	83.33	10	6.67
		95.83	4.17	0	90	10	0
		92.86	7.14	0	66.67	25	8.33
		100	0	0			
	Study Overall	93.94	5.30	0.76	90.24	7.72	2.03
	Population Overall	Agree: 92.16; Neutral: 6.47; Disagree: 1.37					

Time Regulation and Achievement	Team	77.78	11.11	11.11	95.24	2.38	2.38
		91.67	4.17	4.17	88.10	7.14	4.76
		69.05	16.67	14.29	80.56	11.11	8.33
		71.43	21.43	7.14	90	6.67	3.33
		61.11	13.89	25	70	26.67	3.33
		87.50	0	12.50	83.33	13.33	3.33
		64.29	21.43	14.29	86.11	11.11	2.78
		88.89	8.33	2.78			
	Study Overall	74.62	13.64	11.74	85.37	10.57	4.07
	Population Overall	Agree: 79.80; Neutral: 12.16; Disagree: 8.04					

Table 2. Summary of mean results segregated by team, study, and overall sample population levels (n=85) for each of the four factors (Self and Emotions, Synergistic Social Collaboration, Distributed Creativity, and Time Regulation and Achievement).

Mean Scores (Likert Scale 1-7)	
Study 1 (n=44)	Study 2 (n=41)

Factors	Levels	Teams 1 to 8	Teams 1 to 7
Self and Emotions	Team	4.83±0.63	5.29±0.64
		4.81±0.53	5.57±0.53
		5.18±0.46	5.33±0.64
		5.14±0.18	4.90±0.47
		4.38±0.32	4.80±0.58
		4.88±0.40	5.65±0.20
		4.32±0.12	5.21±0.49
		5.17±0.68	
	Study Overall	4.84±0.23	5.17±0.40
Population Overall		5±0.30	
Synergistic Social Collaboration	Team	5.81±0.56	5.82±0.23
		6.10±0.33	5.87±0.30
		5.43±0.45	5.76±0.26
		5.79±0.25	5.67±0.31
		5.28±0.38	5.68±0.36
		5.44±0.36	5.88±0.51
		5.40±0.33	5.39±0.23
		6.07±0.37	
	Study Overall	5.64±0.23	5.73±0.22
Population Overall		5.68±0.20	
Distributed Creativity	Team	5.94±0.45	6.21±0.16
		6.33±0.38	6.38±0.13
		5.67±0.17	6.17±0.27
		5.93±0.29	6.03±0.42
		5.81±0.26	5.70±0.38
		5.71±0.32	6.07±0.35
		5.93±0.26	5.25±0.29

		6.36±0.18	
		Study Overall	5.95±0.16
		Population Overall	5.97±0.14
Time Regulation and Achievement	Team	5.17±0.39	5.69±0.25
		5.71±0.26	5.69±0.38
		4.88±0.31	5.61±0.27
		5.24±0.39	6.00±0.27
		4.89±0.63	5.37±0.27
		5.25±0.32	5.67±0.44
		4.93±0.50	5.86±0.33
		5.83±0.52	
		Study Overall	5.20±0.22
		Population Overall	5.44±0.22

The Levene's test showed equality of variances ($P > 0.05$) for all factors but the Shapiro Wilk test revealed non-normally distributed data ($P < 0.05$) for three factors (Distributed Creativity in studies 1 and 2 respectively; and Synergistic Social Collaboration in study 2). This meant that statistical calculations related to these non-normal distributed groups were subjected to the Mann Whitney U -test and eta squared effect size (η^2) (marked by ^a and ^c in Table 3), and the rest of the normally distributed groups were subjected to the Independent Samples t -test and Cohen's d effect size (marked by ^b and ^d in Table 3). There was no statistical difference on three factors (Self and Emotions, Synergistic Social Collaboration and Distributed Creativity) between the study 1 and study 2 ($P = 0.12, 0.39$ and 0.35 , respectively) (Table 3). However, the factor Time Regulation and Achievement was statistically significant ($P < 0.01$) (Table 3). Effect size estimates showed larger variability between studies 1 and 2 in Self and Emotions and Time Regulation and Achievement ($\eta^2 = 0.34$ and 0.72 , respectively) than in Synergistic Social Collaboration and Distributed Creativity ($d = 0.01$ for both).

Table 3. Summary of statistical results and effect size between studies 1 and 2, for the four individual factors Self and Emotions, Synergistic Social Collaboration, Distributed Creativity, and Time Regulation and Achievement.

Factors	Study	Independent sample t-test or Mann Whitney U-test					Effect Size (Cohen's d or η^2)
		Sample Size (n)	Shapiro Wilk (P)	Levene's test (P)	(P)		
Self and Emotions	1	44	0.26	0.80	0.12 ^a		-0.34 ^c
	2	41	0.31				
Synergistic Social Collaboration	1	44	0.65	0.18	0.39 ^b		0.01 ^d
	2	41	<0.01				
Distributed Creativity	1	44	0.04	0.48	0.35 ^b		0.01 ^d
	2	41	0.01				
Time Regulation and Achievement	1	44	0.44	0.11	<0.01 ^a		-0.72 ^c
	2	41	0.90				

Text in red referred to $P < 0.05$ as statistically significant.

^a referred to independent sample t-test for normally distributed data.

^b referred to Mann Whitney U -test for non-normal distributed data.

^c referred to Cohen's d values based on magnitude of variability of mean values between studies 1 and 2.

^d referred to eta squared (η^2) values based on magnitude of variability of mean ranks between studies 1 and 2.

Thematic analysis

Thematic analysis of the free-text responses identified four main themes: Learning Experiences,

Collaborative Responsibilities, Perceived Skill Development, and Technical Challenges. Quotes are given below to exemplify the open comments.

Learning Experiences

Overall, students **reported positive experiences on the structure, and opportunities** offered by the FLOCC:

“Had a good structure that encouraged participation by all team members of the team” (P#54); “Easy to understand...” (P#02); “Good time allocation” (P#29); and “The challenge we had to solve was interesting and relevant...” (P#43).

They also suggested improvements to the FLOCC, indicating their active involvement and participation:

“Maybe include other aspects and not just healthcare...” (P#08); “I think that the original question was rather broad...” (P#23); and “Timings given could be a bit longer...” (P#56).

Collaborative Responsibilities

Students perceived sharing of thinking processes, information, team diversity and team dynamics as key elements for collaborative creativity. “We could share our thinking process with each other” (P#01); “It gives students an opportunity to work together and exercise teamwork.” (P#24).

There were mixed opinions related to group formation and group diversity: “Interesting mix of people” (P#25); “Forming groups with students with different backgrounds may allow us to have a more fruitful discussion with different points of view...” (P#02).

Perceived Skill Development

Students stated that FLOCC was useful in gaining skills such as design thinking, creativity,

communication, and social learning, and self-reflection:

"I think that the pre team activity materials were very helpful in helping us understand the design thinking process...." (P#28); "Provides a conducive environment for us to think out of the box and come up with novel ideas for issues we think need to be addressed in the healthcare industry" (P#04); "Team activity allowed me to understand different perspectives I haven't considered before" (P#35).

Technical Challenges

As mentioned earlier, because of the Covid-19 pandemic, FLOCC was carried out online. Feedback indicated students – who were very used to online learning at this time – would have preferred face-to-face interactions: "Feel that the discussions were slightly abrupt as they were carried out online" (P#46); "New faces + online (more difficult to share ideas with)" (P#37); and "A digital medium makes teamwork a little more challenging" (P#58).

Discussion

This paper reported the development and evaluation of a novel FLOCC intervention that draws on TBL, PBL and RDT principles to encourage collaborative creativity in medical students. This paper provided sufficient details of the intervention to ensure clarity and replicability. The evaluation data from 85 participants indicate a high level of acceptability for FLOCC. Student responses also suggest that the FLOCC offers students with the opportunity to acquire, hone, and demonstrate their collaborative creativity skills given the right tools, flexibility, and appropriate educational support.

We drew on design thinking principles for the foundation of FLOCC, as recent literature has suggested that design thinking may be an appropriate framework to foster student/patient/practitioners' outcomes such as self-efficacy, learning experiences, and academic

development [49, 51-53]. However, unlike previous studies, we did not base FLOCC exclusively on design thinking principles. Instead, we utilized a blended approach that draws on socio-cultural learning (PBL and TBL) principles to develop a robust conceptual framework. The evaluation results suggest that FLOCC was effective in assisting students in fostering collaborative creativity skills. Furthermore, the adaptation of the ASCC instrument facilitated the measurement the collaborative creativity outcomes [75].

Other studies highlight that more supervision may be appreciated when working with students from different educational backgrounds [52], and that facilitators play an important role in creating a positive learning environment [84]. Hence, we incorporated a specific survey item to measure students' perceptions about the quality of the facilitation received from instructors leading the FLOCC. The qualitative data from the open comments indicated that students valued effective facilitation. Similarly, we added a factor 'Self and Emotions'. Although feelings and emotions can influence the quality of creative outputs [39, 46], these are rarely assesses in design thinking models and collaborative creativity. The importance of these factors to learning was reflected in the students' open comments.

To the authors' knowledge, this is the first study to measure the four factors of collaborative creativity in the context of medical education. This study's new observations were that students (overall population) perceived higher emphasis on Distributed Creativity (92%) and Synergistic Social Collaboration (88%) followed by Time Regulation and Achievement (80%), and Self and Emotions (70%). This suggests that PBL, TBL, and RDT theoretical perspectives, along with selected technologies of FLOCC, enabled a virtual environment where participants could actively engage in teams to practice collaboration, communication, collective knowledge generation, design thinking, and collaborative problem solving. These observations may come from the ability to relate their educational background and experiences to the creativity trigger, and the perceived proximity

from working virtually with other students in the same discipline [85]. On the other hand, prior studies have reported forming interdisciplinary and multidisciplinary teams can be beneficial, depending on the nature of the task [86, 87]. Therefore, it would be interesting to provide a trigger that could be beyond students' educational background and form multidisciplinary teams to measure the effects of the FLOCC process on outcomes of collaborative creativity.

When comparing two studies, results showed no significant differences in any of the variables tested, except those pertaining to Time Regulation and Achievement. This suggests that FLOCC is successful in fostering teamwork and scaffolding the multifaceted creative process, regardless of problem type, time periods, or study population. Based on these findings, the FLOCC structure is robust and may be safe for use in other contexts. Regarding differences in perceived Time Regulation and Achievement, we believe that these differences are a result of the technical difficulties encountered in study 1 and the fact that certain students may find the online environment challenging. Prior research indicated that challenges associated with technology, students, and facilitators are not necessarily barrier to collaborative creativity, but rather as opportunities to enhance it through problem solving, being considerate of others, and appreciating the teacher's effort [30].

Limitations and future research recommendation

There were several limitations in this study. First, it involved volunteer medical students from a single medical school in Singapore. The views of more students at different levels of medical education, and from other medical schools could be gathered in future research. Second, participants were experienced with TBL, self-selecting and may have had more of an interest in design thinking and collective collaboration than typical medical students. Consequently, participants of this study may have different views on group work and differing group decision-making skills. However, the sample size was reasonable for an exploratory "proof of concept" and acceptability study. As is often

the case with online education, it is difficult to separate out student satisfaction with the content and pedagogy of teaching as opposed to the quality of internet connections and technical difficulties [88]. The current evidence is mainly based on the students' self-reported data about their experience with FLOCC. Future research could investigate whether FLOCC is effective and efficient in nurturing collaborative creativity skills for medical education or practice, as compared to established pedagogies such as PBL and TBL.

Realistically, collaborative creativity skills cannot be developed in a short time. Therefore, we suggest that the principles underpinning FLOCC should ultimately be used in a curricular (rather than one-off) basis if fostering collective creativity is a priority in medical education [88].

Implications

FLOCC in the digital environment opened up new possibilities such as the opportunity to understand the 'precise mechanisms' needed to acquire and apply new or innovative knowledge [89]. The framework also underpinned the monitoring of individual and team creativity processes in an organized manner. This is important because if the collection of data is unorganized, comprehending and analyzing the stakeholders' reflections would become challenging and almost impossible to measure and to provide feedback [55]. In the context of medical education and practice, this might influence the past, present and future interpretations of appropriate patient care [64]. Educators can leverage FLOCC as a model to design and modify learning activities that further collaborative creativity and connect the classroom to real-world settings. Testing this framework face-to-face, with other educational intra and inter-disciplines (engineering, sciences, business, and others), and a larger sample size may also form part of future studies.

Conclusions

The FLOCC model, which integrates the design thinking and socio-cultural learning methods (PBL

and TBL), holds considerable promise as a framework for cultivating collaborative creativity in medical education. Further research is needed to evaluate its effectiveness across inter-multi-disciplinary teams and diverse creativity triggers, thereby uncovering its full potential.

Figure Captions

Figure 1. Conceptual underpinnings of the Framework for Learning Online Collaborative Creativity (FLOCC).

Figure 2. Hybrid characteristics of the Framework for Learning Online Collaborative Creativity (FLOCC) based on the strengths of team- and problem-based learning (TBL and PBL), and rapid design thinking (RDT).

Figure 3. The FLOCC (framework for learning online collaborative creativity), represented by the three phases (Inspire, Ideate and Implement) of the rapid design thinking (RDT) model. Individual and team activities were done via asynchronous and synchronous learning, respectively.

Multimedia Appendix of supplementary files (separate attachments to manuscript)

Supplementary Material 1. Pictorial illustration of website.

Supplementary Material 2. Contents of individual Excel Spreadsheet.

Supplementary Material 3. Survey items.

Supplementary Material 4. Contents of team Google Sheets.

Supplementary Material 5. Inputs of Team X to the healthcare sustainability trigger. Note that the blind test sheet indicates the evaluation of the team Y's prototype by team X.

Supplementary Material 6. Inputs of Team X to the Engineering sustainability trigger. Note that the blind test sheet indicates the evaluation of the team Y's prototype by team X.

Declarations

Availability of data and materials

Student responses from the survey were only accessible to the research team (not publicly available) in accordance with ethical requirements by the university. However, findings from the study have been reported or supplemented in the manuscript. Upon reasonable request, details of student responses may be provided following ethical practices of the university to the corresponding author Dr. Sreenivasulu Reddy Mogali (sreenivasulu.reddy@ntu.edu.sg).

Conflicts of Interests

The authors declare that they have no competing interests.

Authors' contributions

SR designed and planned the experiment, collected data, analysed the results, and wrote the manuscript.

TJS designed the experiment, conceived analytical methods, and assisted with writing of manuscript.

PR designed the experiment, facilitated the study, and assisted with the writing of manuscript.

JC contributed to literature review, data analysis and assisted with the writing of manuscript.

SRM conceptualised and designed the experiment, assisted with data analysis and writing of manuscript, and supervised SR.

Acknowledgements

We would like to acknowledge the work of Ms. Ramya Chandrasekaran (R.C.) for participating in mock studies to test the digital tools. We also thank the students who took part in the evaluation.

Funding

This work was supported by the Singapore Ministry of Education, under the grant 'Singapore Ministry of Education Tertiary Education Research Fund' (MOE2019-TRF-027).

Abbreviations

CC: Collaborative creativity

FLOCC: Framework for learning online Collaborative Creativity

TBL: Team-Based Learning

PBL: Problem-Based Learning

RDT: Rapid design thinking

STEM: Science, technology, engineering, mathematics,

DT: Design thinking

ASCC - Assessment Scale for Creative Collaboration

ICT: Information and communication technologies

References

1. Hrynchak P, Batty H. The educational theory basis of team-based learning. *Med Teach*. 2012;34(10):796-801. doi: 10.3109/0142159X.2012.687120.
2. Flexner A. Medical education in the United States and Canada. *Science*. 1910;32(810):41-50.
3. Ferraro F, Etzion D, Gehman J. Tackling Grand Challenges Pragmatically: Robust Action Revisited. *Organization Studies*. 2015;36(3):363-90. doi: 10.1177/0170840614563742.
4. Kamei RK, Cook S, Puthuchear J, Starmer CF. 21 st Century learning in medicine: Traditional teaching versus team-based learning. *Medical Science Educator*. 2012;22:57-64.
5. Mann KV. Theoretical perspectives in medical education: past experience and future possibilities. *Medical education*. 2011;45(1):60-8.
6. Vygotsky LS, Cole M. *Mind in society: Development of higher psychological processes*: Harvard university press; 1978. ISBN: 0674576292.
7. Fernández-Rodríguez CA, Arenas-Fenollar MC, Lacruz-Pérez I, Tárraga-Mínguez R. Teaching Methods in Medical Education: An Analysis of the Assessments and Preferences of Students. *Sustainability*. 2023;15(11):9044.
8. Jones RW. Problem-based learning: description, advantages, disadvantages, scenarios and facilitation. *Anaesthesia and intensive care*. 2006;34(4):485-8.
9. Guilford JP, Christensen PR. The one-way relation between creative potential and IQ. *The Journal of Creative Behavior*. 1973.
10. Stein MI. Creativity and culture. *The journal of psychology*. 1953;36(2):311-22.
11. de Sousa FC. Still the Elusive Definition of Creativity. *International Journal of Psychology: A Biopsychosocial Approach*. 2008 (2):55-82.
12. Daemi H, Moghimi Barforoosh F. Normalization of the creativity test. *Advances in Cognitive Science*. 2004;6(3):1-8.
13. Dietrich A. The cognitive neuroscience of creativity. *Psychonomic bulletin & review*. 2004;11:1011-26.
14. Sternberg RJ, Lubart TI. The concept of creativity: Prospects and paradigms. *Handbook of creativity*. 1999;1(3-15).
15. Kamyli PG, Valtanen J. Redefining creativity—analyzing definitions, collocations, and consequences. *The Journal of Creative Behavior*. 2010;44(3):191-214.
16. Walia C. A dynamic definition of creativity. *Creativity Research Journal*. 2019;31(3):237-47.
17. Smith BL, MacGregor JT. What is collaborative learning. 1992.
18. Iqbal M, Velan GM, O'Sullivan AJ, Balasooriya C. Differential impact of student behaviours on group interaction and collaborative learning: medical students' and tutors' perspectives. *BMC medical education*. 2016;16(1):1-11.
19. Pervaz Iqbal M, Velan GM, O'Sullivan AJ, Balasooriya C. The collaborative learning development exercise (CLed-EX): an educational instrument to promote key collaborative learning behaviours in medical students. *BMC medical education*. 2020;20:1-11.
20. Kopel J, Brower G, Culberson JW. Teaching methods fostering enjoyment and creativity in medical education. *Journal of community hospital internal medicine perspectives*. 2021;11(6):821-4.
21. Miell D, Littleton K. *Collaborative creativity : contemporary perspectives*. London: Free Association Books; 2004. ISBN: 1853437638.
22. Baruah J, Paulus PB. Collaborative creativity and innovation in education. *Creativity Under Duress in Education? Resistive Theories, Practices, and Actions*. 2019:155-77.
23. Hill LA, Brandeau G, Truelove E, Lineback K. Collective genius. *Harvard business review*. 2014;92(6):94-102.
24. Eichbaum Q. Collaboration and teamwork in the health professions: Rethinking the role of conflict. *Academic Medicine*. 2018;93(4):574-80.

25. Moser KS, Dawson JF, West MA. Antecedents of team innovation in health care teams. *Creativity and Innovation Management*. 2019;28(1):72-81.
26. Campion MA, Medsker GJ, Higgs AC. Relations between work group characteristics and effectiveness: Implications for designing effective work groups. *Personnel psychology*. 1993;46(4):823-47.
27. Farh CI, Zhang Y, Long L, editors. Designing creative teams from creative members: Implications for task interdependence. *Academy of management proceedings*; 2015: Academy of Management Briarcliff Manor, NY 10510.
28. Hilliges O, Terrenghi L, Boring S, Kim D, Richter H, Butz A, editors. Designing for collaborative creative problem solving. *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*; 2007.
29. Wheeler S, Waite SJ, Bromfield C. Promoting creative thinking through the use of ICT. *Journal of Computer Assisted Learning*. 2002;18(3):367-78.
30. Gündoğdu B, Ali M. A Systematic review of tech-supported collaborative creativity Practices in the field of education. *Journal of Learning and Teaching in Digital Age*. 2022;7(1):76-89.
31. Paul J, Jefferson F. A comparative analysis of student performance in an online vs. face-to-face environmental science course from 2009 to 2016. *Frontiers in Computer Science*. 2019;1:7.
32. Tutty JI, Klein JD. Computer-mediated instruction: A comparison of online and face-to-face collaboration. *Educational technology research and development*. 2008;56:101-24.
33. Sykes J. Locating the value and opportunities for online collaborative creativity within advertising. *Art, Design & Communication in Higher Education*. 2012;11(2):91-109.
34. Kutaka-Kennedy J. A proposed model to increase creativity, collaboration and accountability in the online classroom. *International Journal of Information and Education Technology*. 2015;5(11):873.
35. Adiloğlu F, Fragiaco F, Petricone F. Distance Artist: Building the Skills of Future Creatives. *Developing Evidence-Based Criteria for Global Virtual Team Tutoring and Management in Art and Design Education*. *The international journal of art & design education*. 2021;40(1):268-82. doi: 10.1111/jade.12336.
36. Fatmi M, Hartling L, Hillier T, Campbell S, Oswald AE. The effectiveness of team-based learning on learning outcomes in health professions education: BEME Guide No. 30. *Medical teacher*. 2013;35(12):e1608-e24.
37. Ma Y, Lu X. The effectiveness of problem-based learning in pediatric medical education in China: A meta-analysis of randomized controlled trials. *Medicine (Baltimore)*. 2019 Jan;98(2):e14052. PMID: 30633204. doi: 10.1097/md.00000000000014052.
38. Reimschisel T, Herring AL, Huang J, Minor TJ. A systematic review of the published literature on team-based learning in health professions education. *Medical teacher*. 2017;39(12):1227-37.
39. Schmidt HG, Vermeulen L, Van der Molen HT. Longterm effects of problem-based learning: a comparison of competencies acquired by graduates of a problem-based and a conventional medical school. *Medical education*. 2006;40(6):562-7.
40. Goswami B, Jain A, Koner BC. Evaluation of brainstorming session as a teaching-learning tool among postgraduate medical biochemistry students. *International Journal of Applied and Basic Medical Research*. 2017;7(Suppl 1):S15.
41. Chan ZC. A qualitative study on using concept maps in problem-based learning. *Nurse education in practice*. 2017;24:70-6.
42. Liao H-C, Wang Y-h. Storytelling in medical education: narrative medicine as a resource for interdisciplinary collaboration. *International journal of environmental research and public health*. 2020;17(4):1135.
43. Macdonald AS. *Design for Health*. ABINGDON: Taylor & Francis Group; 2017. p. 311-27.
44. Waheed J, Jun W, Yousaf Z, Radulescu M, Hussain H, editors. *Towards employee creativity*

in the healthcare sector: Investigating the role of polychronicity, job engagement, and functional flexibility. *Healthcare*; 2021: MDPI.

45. Subeq Y-M. The Importance of Cross-disciplinary Technology Creativity in the Field of Healthcare. *Hu li za zhi The Journal of Nursing*. 2019;66(2):4-5.

46. Koles PG, Stolfi A, Borges NJ, Nelson S, Parmelee DX. The impact of team-based learning on medical students' academic performance. *Academic Medicine*. 2010;85(11):1739-45.

47. Nandi PL, Chan JNF, Chan CPK, Chan P, Chan LPK. Undergraduate medical education: comparison of problem-based learning and conventional teaching. *Hong Kong Medical Journal*. 2000 Sep 2000

2023-03-17;6(3):301. PMID: 2787673130.

48. Yiou R, Goodenough D. Applying problem-based learning to the teaching of anatomy: the example of Harvard Medical School. *surgical and Radiologic Anatomy*. 2006;28:189-94.

49. Sandars J, Goh P-S. Design thinking in medical education: the key features and practical application. *Journal of Medical Education and Curricular Development*. 2020;7:2382120520926518.

50. Li Y, Schoenfeld AH, diSessa AA, Graesser AC, Benson LC, English LD, et al. Design and design thinking in STEM education. *Springer*; 2019. p. 93-104.

51. McLaughlin JE, Wolcott MD, Hubbard D, Umstead K, Rider TR. A qualitative review of the design thinking framework in health professions education. *BMC Medical Education*. 2019 2019/04/04;19(1):98. doi: 10.1186/s12909-019-1528-8.

52. van de Grift TC, Kroeze R. Design thinking as a tool for interdisciplinary education in health care. *Academic Medicine*. 2016;91(9):1234-8.

53. Wolstenholme D, Downes T, Leaver J, Partridge R, Langley J. Improving self-efficacy in spinal cord injury patients through "design thinking" rehabilitation workshops. *BMJ Open Quality*. 2014;3(1):u205728. w2340.

54. Shively K, Stith KM, Rubenstein LD. Measuring what matters: Assessing creativity, critical thinking, and the design process. *Gifted Child Today*. 2018;41(3):149-58.

55. Shimizu I, Kikukawa M, Tada T, Kimura T, Duvivier R, Van Der Vleuten C. Measuring social interdependence in collaborative learning: instrument development and validation. *BMC Medical Education*. 2020;20(1):1-9.

56. Hirtle JSP. Social Constructivism (Coming to Terms). *English Journal*. 1996;85(1):91-2.

57. Palincsar AS. Social constructivist perspectives on teaching and learning. *Annual review of psychology*. 1998;49(1):345-75.

58. Tran VD. Does Cooperative Learning Increase Students' Motivation in Learning? *International Journal of Higher Education*. 2019;8(5):12-20.

59. Huang R, Liu D, Tili A, Yang J, Wang H. Handbook on facilitating flexible learning during educational disruption: The Chinese experience in maintaining uninterrupted learning in COVID-19 outbreak. Beijing: Smart Learning Institute of Beijing Normal University. 2020;46.

60. Mahaux M, Nguyen L, Mich L, Mavin A, editors. A framework for understanding collaborative creativity in requirements engineering: Empirical validation. 2014 IEEE 4th International Workshop on Empirical Requirements Engineering (EmpiRE); 2014: IEEE.

61. Dolmans D, Michaelsen L, Van Merriënboer J, Van der Vleuten C. Should we choose between problem-based learning and team-based learning? No, combine the best of both worlds! *Medical teacher*. 2015;37(4):354-9.

62. Schmidt HG, Rotgans JI, Rajalingam P, Low-Beer N. A Psychological Foundation for Team-Based Learning: Knowledge Reconsolidation. *Acad Med*. 2019;94(12):1878-83. doi: 10.1097/ACM.0000000000002810.

63. Laxman K. A conceptual framework mapping the application of information search strategies to well and ill-structured problem solving. *Computers & Education*. 2010;55(2):513-26.

64. Thakur A, Soklaridis S, Crawford A, Mulsant B, Sockalingam S. Using rapid design thinking to overcome COVID-19 challenges in medical education. *Academic Medicine*. 2021;96(1):56-61.

65. Howard TJ, Culley SJ, Dekoninck E. Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Design studies*. 2008;29(2):160-80.
66. Auernhammer J, Roth B. The origin and evolution of Stanford University's design thinking: From product design to design thinking in innovation management. *Journal of Product Innovation Management*. 2021;38(6):623-44.
67. Kirschner PA, Sweller J, Kirschner F, Zambrano R J. From cognitive load theory to collaborative cognitive load theory. *International journal of computer-supported collaborative learning*. 2018;13:213-33.
68. Brenner W, Uebernickel F, Abrell T. Design thinking as mindset, process, and toolbox: Experiences from research and teaching at the University of St. Gallen. *Design thinking for innovation: Research and practice*. 2016:3-21.
69. IDEO. The field guide to human-centred design: design kit. 1 ed. San Francisco, California: IDEO; 2015.
70. Brown VR, Paulus PB. Making group brainstorming more effective: Recommendations from an associative memory perspective. *Current Directions in Psychological Science*. 2002;11(6):208-12.
71. Beaudouin-Lafon M, Mackay WE. Prototyping tools and techniques. *The human-computer interaction handbook*: CRC Press; 2007. p. 1043-66.
72. Stahl G. The constitution of group cognition. *The Routledge handbook of embodied cognition*: Routledge; 2014. p. 335-46.
73. BUILD. Student Solutions. BUILD's COVID-19 Virtual Design Challenge. 2020.
74. Ayala GX, Elder JP. Qualitative methods to ensure acceptability of behavioral and social interventions to the target population. *Journal of public health dentistry*. 2011;71:S69-S79.
75. Mavri A, Ioannou A, Loizides F. The Assessment Scale for Creative Collaboration (ASCC) Validation and Reliability Study. *International Journal of Human-Computer Interaction*. 2020 2020/07/02;36(11):1056-69. doi: 10.1080/10447318.2019.1709338.
76. Stets J, Turner JH. *Handbook of the Sociology of Emotions*. 1st ed. New York, NY: Springer US : Imprint: Springer; 2006. ISBN: 0-387-30713-3.
77. Tracy JL, Robins RW, Tangney JP. *The self-conscious emotions : theory and research* The self-conscious emotions theory and research. New York: Guilford Press; 2007. ISBN: 9781593854867
1593854862
1-59385-486-2.
78. Bland JM, Altman DG. Statistics notes: Cronbach's alpha. *BMJ*. 1997;314(7080):572-. doi: 10.1136/bmj.314.7080.572.
79. Tomczak M, Tomczak E. The need to report effect size estimates revisited. An overview of some recommended measures of effect size. *Akademia Wychowania Fizycznego w Poznaniu*.
80. Boyatzis RE. *Transforming qualitative information : thematic analysis and code development*. Thousand Oaks, CA: Sage Publications; 1998. ISBN: 9780761909613
0761909613
0761909605.
81. Jebreen I. Using inductive approach as research strategy in requirements engineering. *International Journal of Computer and Information Technology*. 2012;1(2):162-73.
82. Vaske JJ, Beaman J, Sponarski CC. Rethinking Internal Consistency in Cronbach's Alpha. *Leisure sciences*. 2017;39(2):163-73. doi: 10.1080/01490400.2016.1127189.
83. Hajjar S. Statistical analysis: Internal-consistency reliability and construct validity. *International Journal of Quantitative and Qualitative Research Methods*. 2018;6(1):27-38.
84. Ringby B, Duus L. Innovation camp as a method in health education: a study on interdisciplinarity, learning and participation. *European journal of physiotherapy*. 2017;19(sup1):22-4. doi: 10.1080/21679169.2017.1381308.

85. Wilson JM, Boyer O'Leary M, Metiu A, Jett QR. Perceived Proximity in Virtual Work: Explaining the Paradox of Far-but-Close. *Organization studies*. 2008;29(7):979-1002. doi: 10.1177/0170840607083105.
86. Silva A, Leite M, Vilas-Boas J, Simões R. How education background affects design outcome: teaching product development to mechanical engineers, industrial designers and managers. *European journal of engineering education*. 2019;44(4):545-69. doi: 10.1080/03043797.2018.1465029.
87. Stroeken JHM, De Vries MJ. Learning to Deal with Social Factors as a Goal in the Education of Engineers. *European journal of engineering education*. 1995;20(4):447-56. doi: 10.1080/0304379950200405.
88. Raymundo MRDR. Fostering creativity through online creative collaborative group projects. *AAOU journal*. 2020;15(1):97-113. doi: 10.1108/AAOUJ-10-2019-0048.
89. Jarvenpaa SL, VÄaLikangas L. Advanced technology and end-time in organizations: A doomsday for collaborative creativity? *Academy of Management perspectives*. 2020;34(4):566-84. doi: 10.5465/AMP.2019.0040.

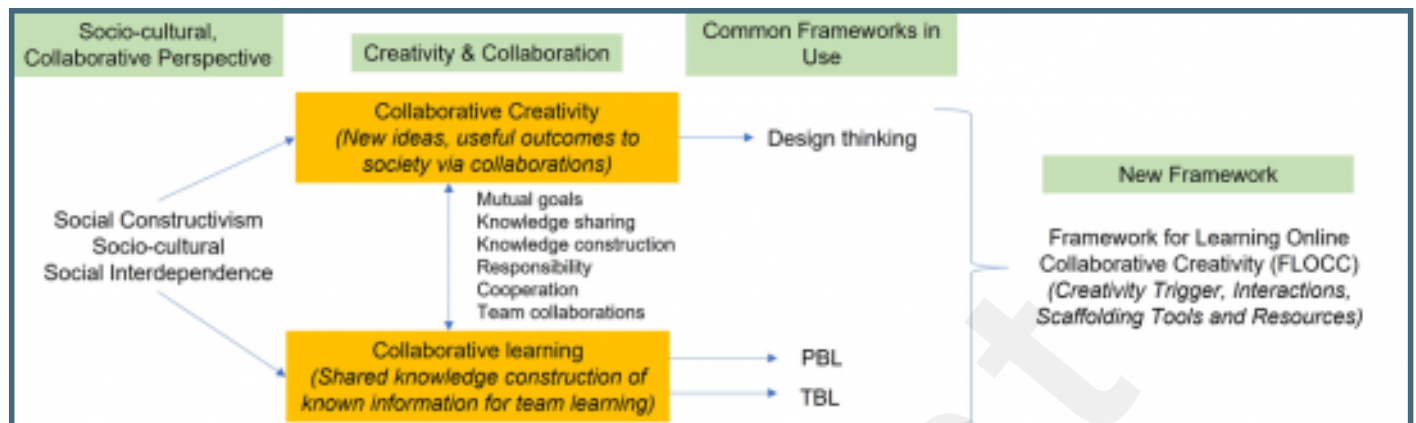
Supplementary Files

Untitled.

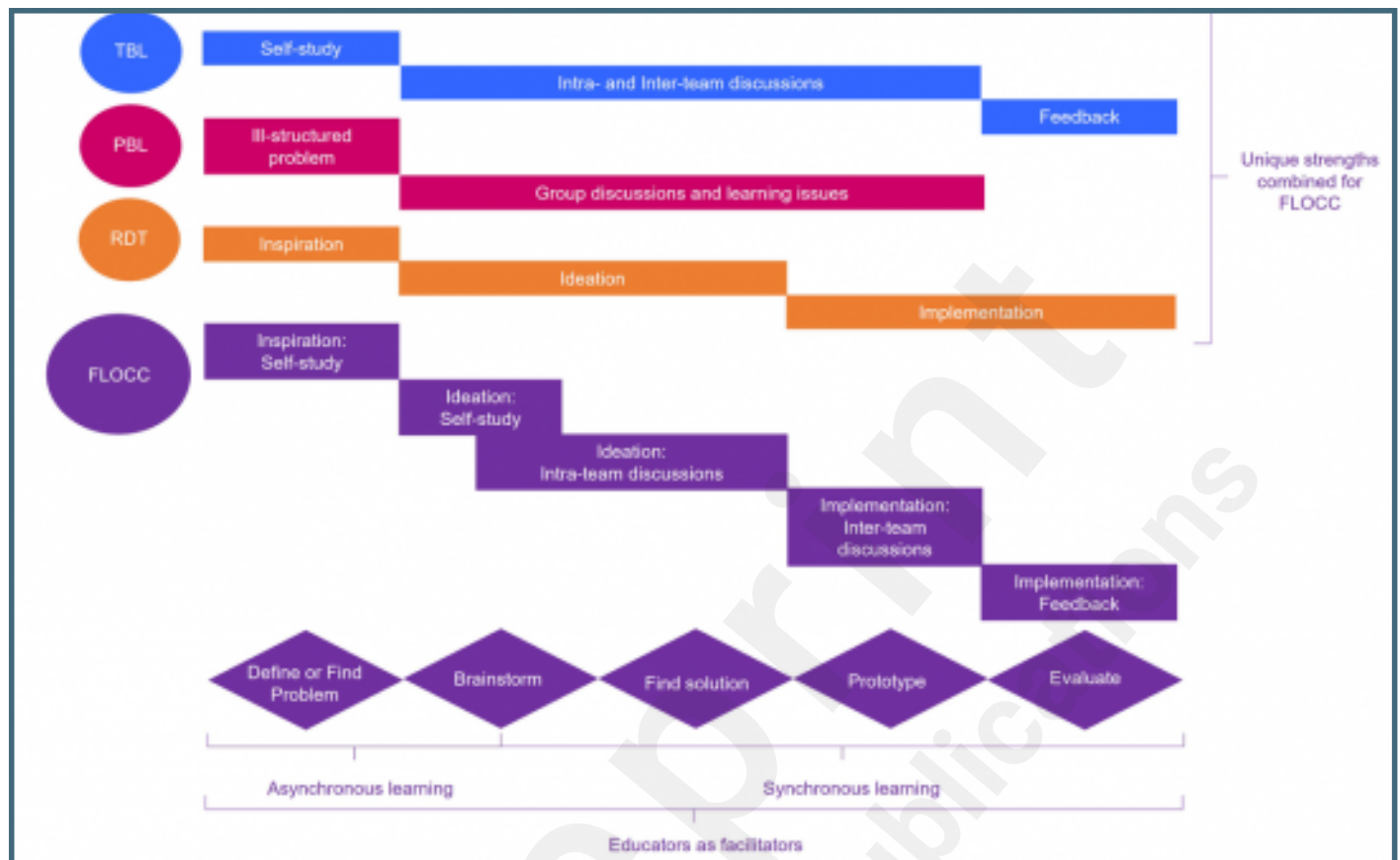
URL: <http://asset.jmir.pub/assets/64a2f72e9ba16672164ed2c42b583a5f.docx>

Figures

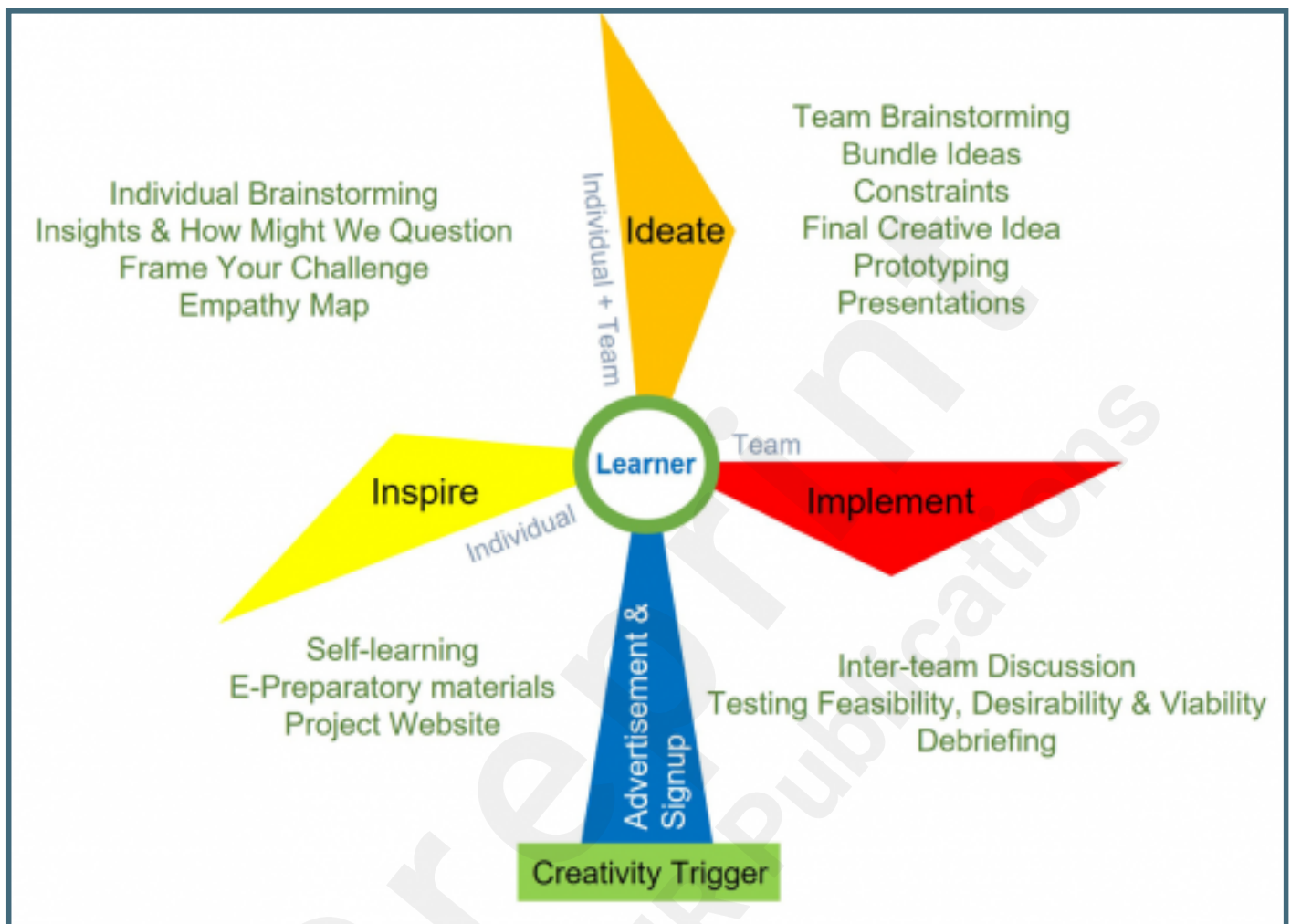
Conceptual underpinnings of the Framework for Learning Online Collaborative Creativity (FLOCC).



Hybrid characteristics of the Framework for Learning Online Collaborative Creativity (FLOCC) based on the strengths of team- and problem-based learning (TBL and PBL), and rapid design thinking (RDT).



The FLOCC (framework for learning online collaborative creativity), represented by the three phases (Inspire, Ideate and Implement) of the rapid design thinking (RDT) model. Individual and team activities were done via asynchronous and synchronous learning, respectively.



Multimedia Appendixes

Pictorial illustration of website.

URL: <http://asset.jmir.pub/assets/d9a47e2ccace9f2ea52e9b8fccd5e650.pdf>

Contents of individual Excel Spreadsheet.

URL: <http://asset.jmir.pub/assets/290ba889b48808eed7ea2b9f0f6b07eb.pdf>

Survey items.

URL: <http://asset.jmir.pub/assets/1909750fdebdb9fce0a6ed7d33d88baf.docx>

Contents of team Google Sheets.

URL: <http://asset.jmir.pub/assets/6324b4cad8381d74ad81419b2d9af6b4.pdf>

Inputs of Team X to the healthcare sustainability trigger. Note that the blind test sheet indicates the evaluation of the team Y's prototype by team X.

URL: <http://asset.jmir.pub/assets/4835264c4978af9e311a6e0ab93e6b13.xlsx>

Inputs of Team X to the Engineering sustainability trigger. Note that the blind test sheet indicates the evaluation of the team Y's prototype by team X.

URL: <http://asset.jmir.pub/assets/b3a9c381f50f3db3c6889d98f035de1c.xlsx>