SOCIALLY SHARED METACOGNITIVE REGULATION IN FACE-TO-FACE COLLABORATIVE PROBLEM-SOLVING: CYCLICAL PHASES, FOCI AND FUNCTIONS

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ABSTRACT

Collaborative problem-solving (CPS) is a vital 21st-century skill. Ill-structured problems demand effective shared regulation from teams to enhance CPS success. While socially shared metacognitive regulation (SSMR) is crucial in CPS, a deeper understanding of its nature is needed. This study investigates the detailed operationalization of SSMR in four teams (N=16), categorized as more successful outcome teams (MSOT) and less successful outcome teams (LSOT). The research spanned over 12 weeks, focusing on ill-structured tasks in a project-based Human-Computer Interaction course. We analyzed 35 hours of video data, capturing teams' verbalized interactions to identify SSMR episodes and coded them for cyclical phases, foci, and functions. Preliminary findings revealed differences between MSOT and LSOT in the number of SSMR episodes, cyclical phases, foci, and functions. Findings shows that achieving better outcomes in CPS requires combining both a cyclical phase in SSMR and a fundamental focus, along with appropriate strategy adaptations, to address internal task challenges effectively. A nuanced analysis of one comparison case (Team 1 vs. Team 4) highlighted the complementary nature of SSMR's function, focus, and cyclical phases and suggested its collective use. Further, a qualitative analysis provides more details about the cyclical phases, foci, and function of SSMR, enhancing the understanding of its nature in MSOT and LSOT. This study contributes to the contextual understanding of SSMR in CPS and underscores its importance for successful collaborative problem-solving.

KEYWORDS

Socially Shared Metacognitive Regulation (SSMR), Collaborative Problem-Solving (CPS), Project-Based Learning, Ill-Structured Problem-Solving, Cyclical phases of SSMR, Foci of SSMR, Function of SSMR

1. INTRODUCTION

A Collaborative problem solving (CPS) in the CSCL environment provides an opportunity to team members to apply their acquired skills and knowledge for a shared task at hand. As different learners are coming from diverse socio-cultural backgrounds, they bring diverse goals, approaches, attitudes, and experiences which become an important and dynamic element during CPS. While problem-solving in a collaborative environment looks attractive for facilitating collective knowledge construction, it's not easy to execute (Lobczowski et al., 2021). Handling the dynamic nature of the team and simultaneously achieving progress in a given problem/task needs many socially shared regulation strategies amongst the collaborating members (Järvelä et al., 2018). In collaborative problem-solving (CPS), team members regulate their cognition, metacognition, motivation, emotion, and behavior through shared metacognitive monitoring (Järvelä et al., 2013). However, cognitive and metacognitive issues may arise due to differences in task and content understanding or different interpretations of the task by team members (Sobocinski, Malmberg, Järvelä, 2022). Hence in CPS shared metacognition plays a vital role in collaboration by making members aware of challenges through shared monitoring processes and highlighting the need for regulation. Learners use different shared cognitive and metacognitive regulation strategies while working on a shared task and those strategies are related to monitoring, controlling, planning, or reflecting (Lobczowski et al., 2021).

Socially shared metacognitive regulation (SSMR) in particular, refers to regulation activities in which different students are simultaneously engaged when monitoring and controlling the group's cognition (Iiskala et al., 2015). SSMR is a crucial phenomenon in CPS as it ensures the appropriate direction of the groups'

cognitive activity using constant monitoring and controlling of the cognitive process. This can refer to activities such as identifying task requirements and expectations (e.g. what has to be done); planning (e.g. time allocation); keeping track of the process and mindfully changing it if needed; monitoring comprehension (e.g. questioning the direction of the cognitive process) or evaluating the quality of the task outcome (Iiskala et al., 2015; Kerrigan et al., 2021). However, the shared regulation is not linear; it involves cyclical phases, making it important to show the detailed nature of the shared regulation (Järvelä, Järvenoja, Malmberg, 2019). This study has captured the cyclical phases and other characteristics of SSMR like foci (focus) and function.

Though there are comprehensive reviews of different forms of regulation (Järvelä et al., 2013) still the SSMR in collaborative processes is described in the general and empirical studies showing that micro-level unfolding of shared metacognitive processes is required (Iiskala et al., 2015). To gain a deeper understanding of the teams' SSMR, this study investigates the occurrences of cyclical phases, focus, and function of SSMR. In CPS, focus refers to the aspects that teams concentrate on during their tasks, which can be fundamental (essential aspects related to the task's goal), organizational (planning and managing task execution pragmatically), or surface (non-essential aspects) (Grau and Whitebread, 2012). The function of socially shared metacognition is to build a shared understanding of the problem by confirming agreed-upon ideas or activating processes to achieve consensus, and to control processes by inhibiting incorrect concepts and redirecting attention appropriately (Iiskala et al., 2011). However, detailed research on operationalizing metacognition in collaborative problem-solving remains limited. The evidence of the SSMR is scarce, and more knowledge is needed to understand what socially shared metacognition is, why it is important for CPS, and how it is operationalized (Vauras et al., 2021).

To investigate the characteristics of SSMR, the research question under investigation is: What are the differences between less and more successful outcome teams in cyclical phases, foci, and function of SSMR during CPS?

2. METHOD

To investigate the SSMR of teams, we chose an authentic semester-long course in Human-Computer Interaction for educational technology (HCI for ET). The course used a project-based learning pedagogy, which involved four milestones (see table 1) and many CPS tasks. Hence the study was conducted over 12 weeks in a graduate-level, face-to-face HCI for ET course in a collaborative classroom setting during Fall 2022. A total of twenty learners consisting of five Ph.D., two Master's learners, and thirteen bachelor's level students (Mean (age) =23.4 years, SD=4.09; 65% Male, 35% Female) participated in this study. None of the participants knew each other before the course and were divided into four teams consisting of 4 members each; each team consisted of Master's, Ph.D., and Bachelor's level learners. The course followed a project-based learning approach in which the following ill-structured problem (design challenge) was given to all the teams - "Design an intervention that supports special needs education (formal/informal) for speech and hearing impaired (DHH: Deaf or Hard of Hearing) students". All teams worked towards designing a solution for the given open-ended problem statement throughout the semester.

After basic orientation, the instructor announced the ill-structured design challenge in class. The semester-long course was divided into four major milestones (See table 3) leading to the final solution. Each task spanned approximately 3 weeks with predefined deliverables contributing to the final solution. For each week, learners were having two 1.5-hour-long in-class sessions. Each team was given the opportunity to collaborate and work on ill-structured problems for a total 8.5 hours in 7 weeks. Each session consisted of the following - (a) half an hour of instruction covering required concepts, tasks, deliverables, and resolving doubts, and (b) one hour for teamwork at the team's dedicated collaborative space (round table). During teamwork, learners discussed the design challenge and task strategies face-to-face and simultaneously documented their progress using the ConceptboardTM platform - a collaborative whiteboard enabling distributed teams to work together - and shared Google Document which contained their design journal. The instructor and TAs visited the teams at their tables whenever needed during teamwork. The course readings corresponding to each week and task were shared with the learners a week prior to the instruction. Learners were briefed about the tasks, associated activities, and deliverables each week as per the weekly course plan.

At the start and end of each milestone, team members were asked to do collective planning and evaluation. This facilitated metacognitive regulation opportunities for the teams while working collaboratively in each milestone. At the end of each milestone, teams were asked to present their team progress to the entire class. They were instructed to log their progress in shared group journals asynchronously (reflecting groups' status and individual contribution).

Table 1. Set of milestones and subtasks given for teams in project-based learning HCI course

Milestone	Task Name
1	Understanding problem & user needs using concept mapping, literature review
	Data gathering using interviews (on-field task)
	Problem definition using a fishbone diagram
	Analysis of user needs using empathy maps and user persona
2	Ideation for the design solution
	Study of existing systems
	Finalizing one idea using a decision matrix
3	Developing low-fidelity prototype
	Mapping prototype with the problem statement and theories
	Checking adherence to learned design principles with prototype
4	Evaluation of prototype with testing matrix and heuristics
	Refinement of prototype based on evaluation

2.1 Data Collection

The data was collected for the four teams and prior consent was taken. The verbal interaction of collaborating team members was video recorded, and the milestone-wise deliverable (performance) was evaluated using the rubric. Learners also worked synchronously and asynchronously outside regular class times, but that part was not recorded. ConceptboardTM board activity screenshots and shared group journals for teams were also collected. However, the solution they have developed, their write ups in group journals, written responses in planning, and evaluation should have been factored in the data analysis.

2.2 Data Analysis

We evaluated the team performance associated with each task using a rubric. All teams were first evaluated task-wise, then the total score was calculated by summing up the task-wise scores. The tasks were grouped logically into different milestones. While doing the task-wise evaluations using a rubric, we have also considered the team's ConceptboardTM screenshots and their shared group journal to validate the work done. This rubric had been shared with all the teams ahead of time. Out of four teams, two teams were placed in a more successful outcome team (MSOT), and two were placed in a less successful outcome team (LSOT). The MSOT (Team 1 and Team 3) scored 9 and 8.14 out of 10, respectively, whereas the LSOT teams (Team 2 and 4) scored 5 and 5.28 out of 10 respectively. We then sampled video data of the first two milestones (first seven weeks) of all four teams. In the first two milestones, various opportunities were given to all teams to decide problem statements and decide probable solution ideas, which were more challenging and involved substantial amounts of brainstorming and decision-making. The first two milestones allowed learners to put forward their thought processes more openly. To investigate the cyclical phases of SSMR and focus on those contrasting teams, we analyzed the video data (of thirty-five hours) from a synchronous face-to-face classroom interaction.

All four teams have chosen the problem statements around the proposed themes. The content analysis approach (Mayring, 2015, p. 95) was followed to analyze students' verbalized interactions during collaborative work. The verbal interactions during CPS were video recorded and transcribed for data analysis. The start points of conversational segments marked by shared metacognitive experiences were identified as trigger events. The endpoint was marked by the last conversational turn on the topic or the emergence of a new trigger (Iiskala et al., 2011). Segments were considered SSMR episodes if they included verbalizations of monitoring and controlling cognitive processes (De Backer et al., 2022). Each episode contained multiple conversational turns by team members. After identifying SSMR episodes from the video

data, we coded the cyclical phases, focus, and function of each SSMR episode using the coding scheme shown in table 2. The reliability of data coding was established using Cronbach's Alpha, the inter-rater reliability method. The deductive coding method is used to code all 103 episodes for four teams. Inter-rater of the coding procedure is done by two educational technology researchers independently in the first round and by discussing and establishing agreement in the second round. We have used 20% samples of each Cyclical Phases, Focus , and Function of SSMR episodes.

Both independent researchers were well-versed in concepts related to metacognition and collaborative problem solving (CPS). Cronbach's Alpha for phases of SSMR is observed as 0.85, for the focus of SSMR is observed as 0.9, and for Function of SSMR is observed as 0.85, which lie between good to excellent band and establishes the reliability of the coding procedure.

Table 2. Deductive coding scheme followed while analyzing SSMR and the degree of transactivity for both teams

Particular	Subtype	Definition
Phases of Metacognitive regulation (De Backer et al., (2015)	Orienting	Students engage in task analysis, which might result in becoming aware of one's task perceptions or activating one's prior knowledge
	Planning	Encompasses selecting and sequencing problem-solving strategies and developing action plans.
	Monitoring	Involves learners' self-judgment upon completion of problem-solving. This can be directed at the learning outcomes, the problem-solving process, or the group members' collaboration.
	Evaluating	Involves quality control of one's learning or problem-solving, aimed at identifying inconsistencies and at optimizing task execution. It also involves monitoring for comprehension, progress, and collaboration.
Focus (Grau and Whitebread, 2012)	Fundamental	Refers to essential aspects discussed to solve the task. It is always related to the final goal of the task. it could include or not include discussions about knowledge.
	Organizational	Students Plan, monitor, change, and evaluate the organization of the task at a pragmatic level.
	Surface	Refers to non-essential aspects of the task, such as time management, choice of resources, etc. They are relevant to complete the task; however, the way this is done does not have a great influence on the quality of the outcomes.
Function (Iiskala, 2011; De Backer, 2022)	Facilitate-Activate	Activating a new direction for ongoing interaction or a new way of thinking in line with and building upon previous activity
	Facilitate-Confirm	Confirm ongoing interaction, eliciting a continuation of previous activity in the same direction
	Inhibit-Change	Changing the flow of collaborative learning, implying ongoing interaction is challenged and current activities are questioned and rethought to the extent that an alternate direction is taken

2.3 Descriptive Statistics

Table 3 presents descriptive statistics for SSMR episodes across four teams, revealing diverse patterns in metacognitive regulation.

Table 3. Descriptive Data showing information about team wise total episodes

	Team 1	**Team 2**	**Team 3**	**Team 4**
Number of Episodes (103)	27	17	32	27
Total Episode Duration	52.43	49.35	78.2	79.45
Min	0.24	0.11	0.17	0.15
Max	8.56	8.7	11.1	10.27
Mean	1.85	2.94	2.32	2.76
SD	2.16	2.5	2.6	2.66

(All data is in Minutes)

The 103 total episodes varied significantly among teams (17 to 32), with notable differences in total duration and average episode length. Episode lengths ranged from 0.11 to 11.1 minutes, with high standard deviations indicating substantial within-team variation. These findings highlight diverse SSMR engagement patterns in terms of frequency, duration, and consistency during collaborative problem-solving.

Table 4 gives team-wise information on different characteristics of the SSMR episodes (such as cyclical phases, foci, and function). Further descriptive statistics are shown in the following table 4, which shows the instances of SSMR episodes, cyclical phases in SSMR, the focus of SSMR episodes, and the function of SSMR episodes. The table 4 grouped teams 1 and 3 as more successful outcome teams (MSOT) and teams 2 and 4 as less successful outcome teams (LSOT), with the last column showing percentage differences based on effect size measures. These measures compare the number of SSMR episodes and key characteristics (cyclical phases, focus, and function) between MSOT and LSOT.

Table 4. Descriptive data analysis for coding team-wise episodes (Showing team-wise cyclical phases, focus, and function of the SSMR)

		Team 1	**Team 2**	**Team 3**	**Team 4**	**MSOT (Team 1 & 3)**	**LSOT (Team 2 & 4)**	**Percentage Difference based on effect size measure (MSOT Vs. LSOT)**
Number of Episodes		27	17	32	27	59	44	34.10%
Number of Cyclical SSMR Processes in episodes. (ex: Mon-Plan or Mon-Eval-Plan)		16	10	28	19	44	36	22.20%
Focus	Fundamental	15	4	25	12	40	16	150%
	Organizational	9	7	7	13	16	20	-20%
	Surface	3	6	0	2	3	8	-62.50%
Function	Activate	8	4	10	19	18	23	-21.70%
	Confirm	6	9	7	0	13	9	44.40%
	Change	13	3	15	8	28	11	154.50%

3. FINDINGS AND DISCUSSION

The differences between MSOT and LSOT concerning their cyclical phases, foci, and functions of SSMR are represented in quantitative and qualitative ways. The contrasting cases allowed us to capture and understand the team-level SSMR processes.

3.1 Data-Driven Distinction: MSOT vs. LSOT

The data shown in Table 4 indicate the measurable differences in the instances of the number of SSMR episodes and the characteristics observed for those episodes in LSOT and MSOT. The percentage difference based on the effect size measure shown in Table 4 reveals that MSOT had 34% more episodes than LSOT. This finding highlights that the identification of critical moments and the formation of regulation responses lead to the occurrence of SSMR episodes, allowing teams to identify the internal challenges of the task (Dindar, Järvelä, & Järvenoja, 2020). The higher number of episodes by MSOT shows that teams 1 and 3 exhibited more regulation behavior than LSOT during CPS. The lower number of SSMR episodes highlights the less frequent engagement in regulatory behaviors during collaborative problem-solving. Overall, MSOT exhibited a higher number of SSMR episodes, aligning with Iiskala (2015), Badhe, Priyadarshini, Dasgupta (2022), and Dindar, Järvelä, Järvenoja (2020).

Furthermore, regarding the phases of SSMR, MSOT had 22% more cyclical phases in SSMR than LSOT. The increased occurrences of cyclical phases in SSMR of MSOT indicate the process of identifying critical moments and becoming aware of discrepancies through shared monitoring. This finding is aligned with

Sobocinski, Malmberg, & Järvelä (2022) and Järvelä, Järvenoja, Malmberg (2019) while underlining that enhanced awareness of gaps in the metacognitive strategy or understanding leads to subsequent planning or evaluation.

The percentage differences shown in Table 4 highlight that the fundamental focus adopted by MSOT was 150% higher than that of LSOT, the organizational focus adopted by MSOT was 20% lower than that of LSOT, and the surface-level focus adopted by MSOT was 63% lower than that of LSOT. The fundamental focus is desirable as it allows teams to understand the essential aspects required to solve the task, whereas organizational and surface-level focuses are not desirable as they involve pragmatic or non-essential components of the task (Iiskala et al., 2011; Grau & Whitebread, 2012). Additionally, regarding the function of SSMR episodes, it was found that MSOT activated 22% fewer new task strategies than LSOT, reevaluated and confirmed the current task strategy 44% more than LSOT, and adapted and changed the current task strategy 154% more than LSOT. This finding related to the function of SSMR indicates that teams should prioritize gaining a fundamental focus while re-evaluating and adapting their existing metacognitive strategies instead of initiating new strategies for each challenge/critical moment (De Backer, 2022).

3.2 Nuanced Analysis: Comparing MSOT (Team 1) with LSOT (Team 4)

We delve into a detailed comparison that reveals the complexities of effective SSMR in collaborative problem-solving. This analysis challenges the simplistic view that more SSMR activity always leads to better outcomes. By comparing Team 1 (from MSOT) and Team 4 (from LSOT), we observed similar numbers of episodes and cyclical processes, with only slight differences in focus. However, the key distinction emerges in the function of SSMR, where Team 1 demonstrates a more balanced and adaptive approach to strategy management. This suggests that having a fundamental focus is important, but it needs to be coupled with the appropriate functions of SSMR to be truly adaptive. While Team 4 frequently activates new strategies, Team 1 shows higher rates of confirming and changing existing strategies, indicating a more reflective and adaptive regulatory process. This comparison underscores that effective SSMR is not about individual metrics but about the interaction and combined use of fundamental focus, and adaptive strategy management (Iiskala et al., 2015), and cyclical phases of regulation. It highlights that successful SSMR requires a blend of persistence in strategy use and flexibility in strategy adaptation, rather than merely increasing the quantity of regulatory activities. This nuanced understanding of SSMR emphasizes the importance of how teams apply metacognitive regulation, rather than simply whether or how much they apply it.

3.3 Contextual Regulatory Distinction: MSOT vs. LSOT

The differences in the SSMR episode level are shown in this section with the help of episodes. This will provide insights into the SSMR process along with contextual information about SSMR in CPS. Shared regulation responses by team 1 (MSOT) and team 2 (LSOT) varied during similar types of tasks. These episodes were captured while all teams were evaluating their work and strategies. The difference in the SSMR is visible in the above episodes of both teams (table 5). In team 1, at the L6, the response given by M3 shows that they all contribute to the discussion and thoughts by individuals also discussed in the group. The next response at L7 by M2 shows the common understanding by team members about how they handle contradictions/conflicts in their opinions and how they get on the same page to achieve a shared goal. Whereas in team 2, at L1 M3 expressed his difficulty with group coordination and not meeting asynchronously if they miss class. As a response to that M1 at L2 has expressed that if you all become particular about a task then group coordination will become better. Here we can say that Team 1 was regulating the challenges regarding tasks being on the same page and Team 2 was regulating group coordination-related challenges having scattered opinions. Team 1 ended up with a fundamental focus whereas Team 2 ended up with an organizational focus.

Team 1 has shown process evaluation MRS in the task performance strategy along with fundamental focus, whereas Team 2 has shown monitoring progress & strategic planning with an organizational focus. De Backer (2022) suggests that diverse responses to similar critical moments or challenging conditions can lead to varying degrees of facilitation for SSMR, which supports this finding. The above findings indicate that teams should gain a fundamental focus while re-evaluating and adapting their current metacognitive strategies rather than activating new strategies for each challenge. Team members need to see the linkages

between sequential actions during task performance and optimize their strategies accordingly. Additionally, teams should aim to gain a fundamental focus while optimizing metacognitive strategies, as merely optimizing strategies with an organizational or surface-level focus will not yield better outcomes in CPS (Iiskala et al., 2015; De Backer, 2022).

Table 5. The difference in phase of SSMR and focus is given for more and less successful outcome teams

Team 1 (MSOT)	Team 2 (LSOT)
(L1) M2- Do we detect and correct errors? (L2) M1- Did we detect something? (L3) M3- and what would be the errors? (L4) M1- Yeah. (L5) M4- Error means it was just an improvement. (L6) M3- I mean we discuss individual thoughts on what we want to do and based on the discussion we decide. (L7) M2- In our group even if we had contradictions still (after making a consensus) we built upon ideas so we didn't reject anyone's idea, (L8) M1- But what to mark here? Neutral..! we are not sure. (L8) All- Yeah. Neutral	(L1) M3- We also don't meet if we miss the class, and to catch up and update the absent person.. (L2) M1- See.. you people (who miss class frequently) have to become more particular, just I have done my part on time, but you people were doing it very late at night, I was observing that live on Document.. but you didn't inform.. (L3) M1- Just like, see, M2 has also not done their respective part.. now I can't fill their columns in this sheet right.. (Unpleasant Feeling of (low) satisfaction). and I have prepared a whole structured sheet for us, and just thought let me take up that responsibility and do it. but you people have to at least put your ideas in it... (L4) M3 - Hmm (Yes) (L5) M1- If you want to meet then just schedule and fix the meeting, let's work. just don't say that we don't meet.. this doesn't work..
Analysis codes: Phase of SSMR: Process Evaluation Focus: Fundamental Function: Confirm	*Analysis codes:* Phase of SSMR: - Monitoring Progress - Strategic planning Focus: Organizational Function: Confirm

Team members negotiated, gathered perceptions about working in a team, and took control of tasks in various ways (Malmberg et al., 2015). For the given RQ, our findings showed that during critical moments in CPS, MSOT, and LSOT responded with different SSMR behaviors, illustrating the differentiated nature of SSMR in CPS. Our findings revealed that MSOT and LSOT differ in terms of cyclical phases, focus, and function of SSMR in different tasks. The data-driven distinction between MSOT and LSOT highlights that, instead of focusing solely on whether a team is applying metacognitive regulation, it is crucial to understand how they apply it. The "how" involves examining the cyclical phases, foci, and functions of SSMR collectively. A cyclical phase in SSMR along with a fundamental focus does not guarantee better outcomes in collaborative problem-solving (CPS), nor do mere adaptations in strategies alone. Both focus and function must be combined to address the internal challenges of the task and facilitate better-regulating opportunities during CPS.

4. CONCLUSION, LIMITATIONS AND FUTURE WORK

This study examined SSMR behavior in collaborative problem-solving tasks among four teams in an HCI course, categorized as MSOT and LSOT based on their performance. These two contrasting groups allow us to capture and understand the team-level SSMR processes in which team members (learners) negotiated, gathered perceptions about working in a team, and took control of the tasks in various ways. Findings reveal distinct SSMR patterns between these groups. LSOT demonstrated insufficient regulatory engagement, focusing more on surface-level aspects and showing inefficient strategy management. In contrast, MSOT exhibited more effective identification of critical moments and formation of regulation responses. We have presented sample episodes (table 5) to show the contextual regulatory distinction between MSOT and LSOT, which enhances the detailed understanding of SSMR behavior in these two groups. We also examined a comparison case of MSOT (Team 1) and LSOT (Team 4), which revealed critical differences in their SSMR behavior, despite having similar numbers. This examination provided a nuanced understanding of SSMR in collaborative problem-solving. While both teams exhibit similar numbers of episodes and cyclical processes,

the key difference lies in the function of SSMR. Team 1 showed a more balanced and adaptive approach to strategy management, emphasizing the importance of not just the frequency but the nature of SSMR activities. These findings contribute to a nuanced understanding of SSMR's role in enhancing collaborative problem-solving effectiveness. This study also advances the understanding of SSMR in CPS by detailing its operationalization and unfolding processes. By identifying cyclical phases, foci, and functions of SSMR, our findings provide a premise for developing targeted support strategies to enhance SSMR in CPS contexts.

While this study adds valuable insights into metacognition in collaborative settings, it has limitations. Some teams may have worked outside the classroom, and their fieldwork was not recorded. Future research can consider capturing asynchronous interactions and include more data sources for comprehensive analysis. The small number of participants and potential confounding variables like individual motivation and task interest may impact SSMR. Increasing participant numbers and ensuring diverse samples will enhance the generalizability of findings. Replicating the study in various educational contexts will test the findings' applicability.

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