International Society of the Learning Sciences

Investigating the Relationship Among Solution Quality, Group Variability in Science Confidence, and Reciprocal Participation in Online Science Collaborative Problem-Solving Tasks

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Abstract: The current study examines how group variability in science confidence interacts with perceived reciprocal participation to influence group's solution quality. Thirty-five groups of four adults worked collaboratively on nine science tasks in an online synchronous setting. Surveys were used to gather data on each member's science confidence level and perceived reciprocal participation. We found a significant interaction effect of group variability in science confidence and reciprocal participation on solution quality. Further analyses showed that for groups with low variability in science confidence, the more variability in reciprocal participation, the lower the solution quality they generated. However, the finding for the groups with high variability in science confidence was the opposite – the more variability in reciprocal participation, the better solution quality they generated. The current study underscores the importance of science confidence in collaborative problem-solving activities.

Introduction

Research has suggested the importance of exposing students to numerous collaborative problem-solving tasks in science classrooms. Such activities positively influence learning outcomes (Bungum et al., 2018) and other crucial skills, such as metacognitive self-regulation (Chen & Chiu, 2016) and scientific argumentation (Nichols et al., 2016). However, several studies have acknowledged the challenges of implementing effective collaborative problem-solving because it relies on several factors. Research has indicated that enabling effective collaborative problem-solving relies on (a) group composition (e.g., Kallery & Loupidou, 2016); (b) students' individual and shared learning regulation (Järvelä & Hadwin, 2013); (c) relational and communication skills (Kutnick & Blatchford, 2014); and (d) levels of scaffolding provided for students (Chen & Chiu, 2016). In the current study, we focused on how group composition— particularly the heterogeneity of group members' science-confidence levels—interacts with perceived reciprocal participation (i.e., group members' perceptions of their contribution in providing and receiving clarification, feedback, and help during collaborative problem-solving) during collaboration to influence the groups' quality of solutions.

Several studies have explored heterogeneity's influence on group performance (e.g., Kallery & Loupidou, 2016). However, little is known about the interaction effect of group variability in science confidence and perceived reciprocal participation on the quality of solutions generated collaboratively. Based on the socio-cognitive theory of learning, confidence in an academic subject or content area influences and is influenced by cognitive ability or prior knowledge (e.g., understanding of scientific concepts). Consequently, in a science collaborative problem-solving setting, productive scientific argumentation and discussion are desired and have been found to depend on prior knowledge, confidence, and familiarity with science topic areas (Grooms et al., 2018). Thus, members' science confidence is integral in such a collaborative setting.

In the current research, we conducted a clinical study with 35 groups of four adult individuals working collaboratively on nine science tasks in a synchronous online environment. We aimed to gain more evidence on how heterogeneity in science confidence interacts with reciprocal participation to influence solution quality. The three research questions guiding this study are as follows: (1) To what extent does group variability in science confidence correlate to solution quality generated through collaboration?; (2) To what extent does group variability in perceived reciprocal participation correlate to solution quality generated through collaboration?; and (3) Does the interaction of group variability in science confidence and perceived reciprocal participation affect the solution's quality generated through collaboration?

Methods

Participants and Context. A total of 35 groups with four members each participated in the current study. We recruited these adult participants (age $M = 30.88$, $SD = 11.88$) via email. They comprised a broad range of occupations: graduate students, freelancers, engineers, teachers, attorneys, and retirees. Demographically, 60% of the participants were female, 26% male, and 14% identified as non-binary. In addition to gender, 40% of the participants were White, 31% Asian, 21% Hispanic/Latinx, 6% Black/African American, 1% Native American, and the remaining 1% identified as Other. Of these participants, 37% reported speaking one or more languages other than English at home. Regarding group information, 60% of the groups were mixed gender, and 69% were multi-racial. In addition, 71% of the groups had at least one multilingual member. The groups collaborated for a total average of 45 minutes to solve nine science tasks. Each group collaborated in a synchronous online environment through the video conferencing platform Zoom.

Scoring Solution Quality and Instruments. The participants completed two surveys: one before collaborating and another when finishing. The science-confidence data of each participant were collected as part of the pre-collaboration survey, and the perceived reciprocal participation data were collected as part of the post-collaboration survey. **Science Confidence**. We asked participants to rate their confidence in five science concepts: photosynthesis, cellular respiration, energy and matter, ecosystem, and earth and space science. **Perceived Reciprocal Participation**. We adopted an instrument developed by Dewiyanti et al. (2007) to measure each participants' perceptions of their reciprocal participation during collaboration. An example item included "I asked for an explanation if other group members gave unclear feedback." The instrument had a Cronbach's alpha value of .841, indicating satisfactory reliability. To obtain the data on group variability in science confidence and perceived reciprocal participation, we calculated the standard deviation (*SD*) based on the four participants' average scores. We used this *SD* value for each group to define the group variability in science confidence and perceived reciprocal participation. **Scoring Solution Quality**. We developed a rubric, and two coders scored the solution quality together. Any disagreements were discussed until they reached a consensus. Hence, we did not compute any inter-coder reliability. **Covariate: Variability in Group Working Opinion**. We wanted to control for group variability in the group working opinion. Participants' group working opinions were measured with an instrument using developed by Dewiyanti et al. (2007). Scale item included "Working in a group is motivating" and "Working in a group is challenging" (reversed item). This instrument had a Cronbach's alpha of .848.

Data Analysis. Pearson's correlation test was run to observe the associations among the variables. The results from these correlation tests were used to answer RQ1 and RQ2. We used multiple regression tests to answer RQ3. Two regression models were tested. Model 1 consisted of all variables without an interaction effect. Model 2 consisted of all variables in Model 1 and an interaction effect of group variability in science confidence and perceived reciprocal participation. If we identified an interaction effect, we then used Model 2 to generate the graph of interaction effect on the dependent variable (i.e., group solution quality score).

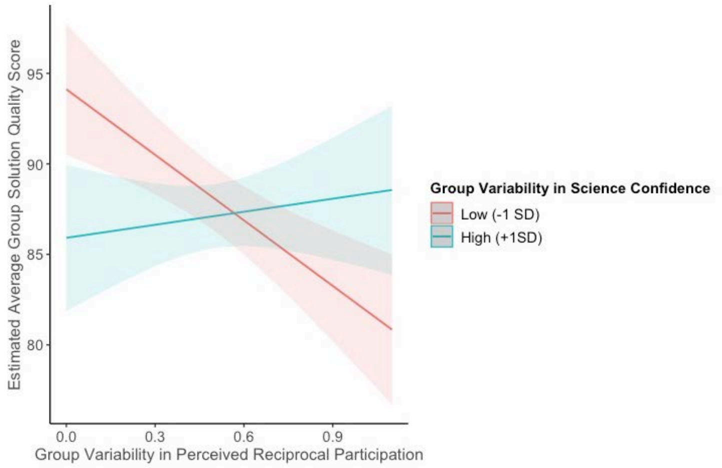
Table 1
Full Regression Models: with and without an Interaction Effect

Variable	Model 1: Without Interaction Effect			Model 2: With Interaction Effect		
	b	*t*	*p*	*b*	*t*	*p*
Intercept	85.60	17.90	< .001	95.54	19.44	< .001
GV in Age	0.03	.20	.842	0.11	0.78	.444
Group Mixed Gender Status^S	-2.54	-1.68	.105	-2.54	-1.89	.070
Group Ethnically Diverse Status^S	2.99	1.89	.070	3.66	2.56	.017
Multilingual Member(s) in Group^S	-0.36	-0.23	.821	-0.04	-0.03	.980
GV in Science Confidence	-1.76	-0.45	.656	-21.04	-2.77	.010
GV in Group Working Opinion	3.06	0.56	.581	3.62	0.74	.465
GV in Perceived Reciprocal Participation	-5.81	-2.22	.035	-21.35	-3.61	.001
GV in Science Confidence x GV in Perceived Reciprocal Participation	-	-	-	37.11	2.85	.008
R (*R*$_{adj}$)	.28 (.10)			.45 (.29)		
F-value (*df*)	1.53 (27)			2.71 (26)		
p-value	.201			.026		
Δ*F* (Δ*df*)	-			1.18 (1)		
p-value for Δ*F*	-			.391		

Findings

Based on the correlation tests, we found that group variability (GV) in Science Confidence did not significantly correlate with the Group Solution Quality Score ($r = .09$, $p > .05$). However, we found that GV in Perceived Reciprocal Participation significantly correlated with Group Solution Quality Score ($r = -.34$; $p = .045$), and the correlation coefficient was negative. These findings hence answered the first and second research questions. Following these results, regression tests were run, and the results are presented in Table 1. First, a regression model without interaction effect (Model 1) was performed first to investigate the main effect of each predictor, including the covariates. Based on Model 1, only GV in Perceived Reciprocal Participation was the significant predictor ($p < .05$) of Group Solution Quality Score. In Model 2, we found a significant interaction effect of GV in Science Confidence and GV in Perceived Reciprocal Participation on Group Solution Quality Score. We also found that Group Ethnically Diverse Status positively predicted Group Solution Goal, indicating that the more ethnically diverse a group, the better the group's solution quality. Figure 1 illustrates that for a group with low variability in science confidence (i.e., group members have relatively similar science confidence), the greater the variability in perceived reciprocal participation (i.e., group members had differing perceptions of their own reciprocal participation), the lower group-solution quality the group generates. However, these variability results did not show whether participants had high vs. low science confidence—low variability could be attributed to two cases: all group members had high science confidence, or they all had low science confidence. Thus, we investigated further by calculating the aggregate mean of group scores on science confidence. The result was 1.96 out of 3 (*SD* = 0.25), indicating that most groups had relatively moderate-high science confidence.

Figure 1
The Interaction Effect between Group Variability in Science Confidence and Group Variability in Perceived Reciprocal Participation on Group Solution Quality Score (Based on Model 2)



Regarding the group with high variability in science confidence, we found that the greater the variability in perceived reciprocal participation (i.e., group members had differing perceptions of their own reciprocal participation), the better solution quality the group generates. In addition, based on Figure 1, the results also implied that groups with low variability in science confidence (i.e., all group members have relatively similar science confidence) and low variability in perceived reciprocal participation (i.e., all group members have relatively similar perceptions of their own participation during collaboration) would generate the best solutions. Again, low variability in perceived reciprocal participation can consist of two cases: either all group members think they actively participated, or all group members do not think they actively participated. Thus, we followed up by calculating the aggregate mean of group scores on perceived reciprocal participation. The average was 3.75 out of 5 points (*SD* = 0.33), indicating that most participants believed they actively participated during the collaboration. Therefore, for the context of the current study, both low group variability in science confidence and perceived reciprocal participation can be interpreted in the context of high confidence and high reciprocal participation groups.

Discussion and conclusion

The current study's primary purpose aimed to uncover the interaction effect of GV in science confidence and perceived reciprocal participation on solution quality generated in a series of science collaborative problem-solving activities. Our study findings suggest two types of group configuration that can be adopted to maximize the solution quality generated collaboratively. The first configuration is when all students in a group have the same level of science confidence (particularly, relatively high) and when all students also have relatively similar chances to participate during the collaboration process (clarifying and providing feedback). Such a group would be the one that generates a better-quality solution. This type of group composition may also create what González et al. (2003) called group cohesion characterized by social and task cohesion.

The second group configuration that may maximize the solution quality is when a group comprises members with different levels of science confidence and when the members have different chances to participate. This configuration allows group tutoring. Thus, members with higher science-confidence levels (presumably higher science knowledge) have more opportunities to explain and clarify concepts to members with lower science-confidence levels (and presumably lower science knowledge). Therefore, in this kind of group configuration, a relatively steep learning curve arises for the members with lower science confidence, which allow the groups to engage in activities that maintain productive struggle events leading to a better solution quality.

Although the current study was situated in a laboratory setting, we believe that our findings have implications for both K–16 and professional education. For instance, when science teachers implement collaborative learning in a formal K–12 setting, they tend to create student groups based on students' varying levels of science knowledge. Although assessing student science knowledge at the beginning of units is sometimes logistically feasible, teachers often lack sufficient time to gather students' conceptual understanding; diagnosing students' knowledge is labor-intensive. Instead, teachers can use one simple question that asks them to rate their confidence in the science concepts to be learned. Student groups can then be formed based on this confidence level. If students form their own groups after teachers gather confidence-level information, the teachers can also guide these student groups to ensure cohesion is maintained.

We urge the readers to carefully interpret the findings due to several limitations. These limitations include but not limited to study's context, which is situated in a laboratory setting, and small sample size. For future studies, we believe that conducting qualitative analysis and presenting episodes of how members of a group based on science confidence interact during science collaborative problem-solving activities. We believe such data and analysis can substantiate the current study findings.

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Acknowledgments

This work is funded by National Science Foundation grant #2016849. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The portion of this study was funded by an internal research and development grant at SRI International.