Exploring the Role of Prior Knowledge and Group Action Synchrony in Sixth Graders’ Game-based Collaborative Learning

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Abstract: Group action synchrony is often used as an indicator to assess how similarly group members behave in the collaborative game-based learning. Previous study showed the group action synchrony as a key factor to learning gain. However, its intertwined relationship with learners’ prior knowledge has not yet been largely explored. Therefore, this paper examines the relationship of three different levels of prior knowledge (individual, group, and within-group difference level) and group action synchrony with individual and group learning performances. We particularly used game logs and pre-and post-knowledge test scores of 65 groups from 139 students. Our findings indicate that group action synchrony and prior knowledge at individual and group level are critical to predicting individual learning performance. Similarly, group learning performance is positively predicted by group action synchrony and prior knowledge at group level.

Background

Collaborative learning has become an increasingly important mode of learning in the K-12 settings, especially in science learning. With the ubiquitous use of new technology, digital learning environments have been utilized to support students’ domain knowledge and socio-emotional skills. Within the field of computer supported collaborative learning (CSCL), the use of computer-based systems brings new ways to make sense of how students’ collaborative process and their learning outcome. In this paper, we examined prior knowledge and group action synchrony as two factors in understanding collaborative learning in a game-based learning environment.

Prior literature pointed out prior knowledge at individual and team levels serves as a key factor to explain individual learning in collaborative settings. For example, Zambrano et al. (2019) revealed that the teams consisting of high prior knowledge individuals showed more knowledge acquisition than those consisting of low prior knowledge individuals. Moreover, Slof et al. (2021) demonstrated higher prior knowledge at team level was a significant predictor to individual learning at the collaborative setting. Despite continuous efforts to consider students’ prior knowledge in designing collaborative learning environment, the role of asymmetric prior knowledge within a team is still inconsistent in previous research. In fact, Kirschner et al. (2009) reported that heterogeneity in groups regarding students’ prior knowledge (e.g., high and low-prior knowledge students in a group) lead to different collaborative learning processes (i.e., promoting dynamic knowledge sharing or inducing unnecessary transaction costs), depending on whether group members reach to the group synchrony in shaping shared understanding.

As a key component of shared understanding in a game-based learning, we adopt *group action synchrony* (Kang et al., 2019) in this study, which can be operationalized as the degree of similarity to group members’ observable behavior sequences. This concept in game-based learning enables us to identify users’ collaboration patterns from system generated data such as users in game behaviors from streaming game log. Moreover, the synchrony among group members’ behaviors can be quantified as a univariate metric (e.g., *Jaccard* coefficient); thus, we can enter this variable as a proxy of the quality of group collaboration. In fact, our previous study (Kang et al., 2019) showed that the game action synchrony served as a key indicator to trace collaborative processes which were related to learning gain. However, we did not examine the relationship between the different level of prior knowledge and the degree of group action synchrony. It is critical to consider both factors as they are substantially intertwined in the process of collaboration (Slof et al., 2021). We address the gap in this follow-up study. Specially, this study is guided by the following questions: to what extent the prior knowledge (i.e., prior knowledge at the level of individual, group, and within-group differences) and group action synchrony can predict individual learning performances (RQ 1) and group learning performances (RQ 2) in a science learning game environment.

Method

Participants and settings

A total of 139 six graders (47.4% female) were recruited from a middle school in the Southwestern area of the United States. The students were encouraged to work in small groups (n = 65), while everyone had individual computer access. They played a science learning game, *Alien Rescue*, during regular scheduled class as a part of their classroom activities. *Alien Rescue* is science learning game that is designed for students to solve a scientific problem and learn about the solar system. In this open-ended game, students play the role of youth scientists who are tasked to rescue six alien species displaced from different place in fictional galaxy. Students explore different ways to find new homes in our solar system for each alien species, using different tools embedded in the game environment. During the gameplay, students will gain experience and develop strategies of problem-solving by going through multiple solution paths, including finding evidence, matching information, and formulating rationale. Before starting to play the game, the students were asked to complete a demographic survey and take a pre-Space Science Knowledge Test (SSKT) that measures students' understanding of factual knowledge of space science that aligns with what they learn in the game. The students began to explore the game environment, learn different in-game tools, and work on potential solutions. Students played the game during six sessions, and they were asked to identify solutions by finding scientific evidence, generating arguments and their rationales for each alien species' suitable homes. After completing all game sessions, all the students were asked to take a post-SSKT, which had the same items with the pre-SSKT, for 30 minutes.

Measurements

Learning performances

For individual learning performance, we used post-SSKT scores. The SSKT comprises 24 items, and the score range was from 0 to 24 (1 point per each item). The internal reliabilities of the test were calculated by Cronbach's α which was .77 for a pre-test and .83 for a post-test. For group learning performance, we used the total number of students' solutions generated by each group members. The solutions were scored by a rubric used in the study by Kang et al. (2017). We adopted solution scores as a group performance rather than the aggregated post-SSKT for the group. The reason is that this measure reflects the process in which learners solved communal tasks with their group members.

We used the pre-SSKT scores to calculate three different types of prior knowledge. First, we used a raw pre-SSKT score as (1) prior knowledge at the individual level and averaged pre-SSKT scores per group as (2) prior knowledge at the group level. Lastly, we computed a Gini coefficient – the degree of equality in distribution - based on group members' pre-SSKT scores for (3) within-group differences regarding prior knowledge. The range of the metric was from 0 to 1; when within-group difference is closer to 0, group members' pre-SSKT scores are identical.

Group action synchrony

The game log data consist of the following information: students' identifiers, a set of game action logs and timestamps (e.g., open, click and navigating), and interaction records among group members. To quantify group action synchrony at group level, we calculated the similarity of each group members' game tool usage using a *Jaccard coefficient metric* (see more details in Kang et al., 2019). The range of the metric was from 0 to 1, indicating that 0 is completely different but 1 is totally identical among group members' game behaviors. Due to the missing data in the last session, we selected and calculated the metric for the first five sessions and then averaged these five values as a *group action synchrony*.

Gender

Although gender is not our research main interests, we entered gender at the individual and group level to control its potential effect on outcome variable. We used gender information included in the background survey. In case of gender composition at the group level, we coded to three sub-categories according to gender composition within a group (i.e., group gender): male only, female only, and mixed gender.

Model building

To answer RQ 1, we build a model to exam how individual learning performances (n = 139) are associated with individual and group level-variables. We employed a two-level model to analyze the data since individuals are nested in a group (Level 1: individual, Level 2: group) and potentially affected by group features. In fact, the result from null model demonstrated that ICC (intraclass correlation coefficient) was 0.371, indicating that around 37% of variance was from group level and around 63% was within individuals. Regarding RQ 2, to explore how group features are associated with group learning performances (n = 65), a multiple regression was performed.

Results

RQ 1. Prior knowledge and synchrony relation with individual learning performances

The result (see Model 3 in Table 1) showed prior knowledge at the individual level (Level 1; $\beta = 0.59$, $p = 0.016$) predicted individual learning performance. Regarding the group level (Level 2), two variables, prior knowledge at the group level ($\beta = 0.25$, $p = 0.049$) and group action synchrony ($\beta = 4.37$, $p = 0.023$), were significant predictors for individual learning performances.

Table 1
Multilevel modeling results for individual learning performances

	Null Model		Model 1		Model 2		Model 3	
	β	*SE*	*β*	*SE*	*β*	*SE*	*β*	*SE*
				Fixed effects				
Intercept	12.75*	0.45	5.12*	0.70	5.36*	0.70	2.68*	1.25
Level 1 (Individual Level)								
Gender (reference: Female)			-0.44	0.54	-0.58	2.02	-3.92	1.97
Prior knowledge at individual level			0.77*	0.06	0.74*	0.06	0.59*	0.09
Level 2 (Group Level)								
Group gender (reference: Female only)								
Male only					3.40	2.11	3.53	2.04
Mixed gender					-0.10	1.52	-0.40	1.48
Group action synchrony							4.37*	1.87
Prior knowledge at group level							0.25*	0.13
Within-group difference							-0.69	3.54
				Random effects				
Variance components								
Intercept	7.11		0.32		0.42		0.38	
Residuals	12.04		8.62		8.20		7.67	
				Goodness of fit				
AIC	781.24		693.76		692.67		689.33	
BIC	789.98		708.33		713.06		718.46	
Log-likelihood	-387.62		-341.88		-339.34		-334.66	

* $p < 0.05$; Within-group difference at Level 2 refers to within-group differences regarding prior knowledge.

RQ 2. Prior knowledge and synchrony relation with group learning performances

The results were in line with the results of RQ 1 in that group action synchrony and prior knowledge at group level were significant predictors to group performance (see Model 3 in Table 2). Specifically, the results indicated that there were significant main effects of prior knowledge at the group level ($\beta = 0.33$; $p < 0.001$) and group action synchrony ($\beta = 4.71$, $p = 0.016$). On average, predictors explained 28.6% of variance in the model, $R^2 = 0.286$, $F(5, 59) = 4.72$, $p < 0.001$.

Table 2
Hierarchical regression results for group learning performances

	Model 1		Model 2		Model 3	
	β	*SE*	*β*	*SE*	*β*	*SE*
Intercept	0.91*	0.27	-2.38	1.23	-4.05*	1.26
Group gender (reference: Female only)						
Male only	0.62	0.60	-0.22	0.59	-0.14	0.56
Mixed gender	0.30	1.24	0.45	1.14	-0.04	1.11
Within-group difference			0.74	3.71	-0.12	3.58
Prior knowledge at group level			0.34*	0.09	0.33*	0.09
Group action synchrony					4.71*	1.89

* $p < 0.05$; Within-group difference refers to within-group differences regarding prior knowledge.

Discussions and future directions

This paper builds upon two foci of research in collaborative learning: the role of prior knowledge and group action synchrony. We investigated to what extent different levels of prior knowledge—the levels of individual, group and within-group difference—and behavioral convergence are associated with individual learning performance in the game-based collaborative learning context.

First, our finding revealed that group action synchrony was a significant predictor to both individual and group learning. When the game behavioral patterns within a group showed more similarity, all group members achieved higher scores in scientific knowledge, compared to groups with more different game behavior pattens. A possible explanation could be that compared to traditional CSCL settings, a science learning game, such as *Alien Rescue*, is characterized not only as a contextual space to promote learning engagement but also as a cognitive tool to facilitate mutual references, negotiate about conflicted problem-solving strategies and then generate shared solutions. In this context, seeking to learning resources embedded in game and carrying out communal tasks through adjusting their game actions in a similar way promote each group member's shared understanding, ultimately leading to considerable scientific knowledge gain (Sinha et al., 2015).

Regarding the role of three different levels of prior knowledge in collaborative learning, prior knowledge at the individual and group levels significantly predicts individual learning, but within-group difference did not (RQ 1). Similarly, group learning performance was positively predicted by prior knowledge at group level, but not within-group difference (RQ 2). As for prior knowledge at individual level, our analysis is consistent with previous studies in that domain knowledge possession of each team members prior to collaboration phase has a critical factor to individual knowledge acquisition in collaborative inquiry (Gijlers & de Jong, 2005). The results at the group level indicate that having students with higher prior knowledge 'on average' work together within a group matters in individual and group learning performance, regardless of group members' prior knowledge differences. When the group formation is 'high-high' prior knowledge students or 'high-low' prior knowledge students, they showed individual and group learning performance better than groups consisting of only low prior knowledge students. This is aligned with Webb's (1991) findings that when groups comprised only lower ability learners, they barely generate explanation giving in the group discussions. These analyses give implications on how to form groups based on prior knowledge to promote individual and team learning in the collaborative game-based learning.

One of the limitations we have identified is that using game logs as a main data source enabled to trace group synchrony and examine its role in individual and team learning achievements but limited to understand "how" and "why" it happened. This calls for future studies of investigating in-depth observational data (e.g., videos or audios) collected during game play to advance our empirical insights of group action synchrony. Our study also yields design implications for a collaborative and open-ended game-based learning environment, such as Alien Rescue, in which learners learn scientific knowledge through collaboration by themselves without explicit scaffoldings. Future designs should also consider adding scaffolds for groups consisting of students with low prior knowledge.

References

Gijlers, H., & de Jong, T. (2005). The relation between prior knowledge and students' collaborative discovery learning processes. *Journal of Research in Science Teaching, 42*(3), 264-282.

Kang, J., An, D., Yan, L., & Liu, M. (2019). Collaborative problem-solving process in a science serious game: Exploring group action similarity trajectory. In C. F. Lynch, A. Merceron, M. Desmarais, & R. Nkambou (Eds.), *Proceedings of the 12th international conference on educational data mining* (pp. 336–341). International Educational Data Mining Society.

Kang, J., Liu, M., & Qu, W. (2017). Using gameplay data to examine learning behavior patterns in a serious game. *Computers in Human Behavior, 72*, 757-770.

Kirschner, F., Paas, F., & Kirschner, P. A. (2009). Individual and group-based learning from complex cognitive tasks: Effects on retention and transfer efficiency. *Computers in Human Behavior, 25*, 306–314.

Sinha, S., Rogat, T. K., Adams-Wiggins, K. R., & Hmelo-Silver, C. E. (2015). Collaborative group engagement in a computer-supported inquiry learning environment. *International Journal of Computer-Supported Collaborative Learning, 10*, 273–307.

Slof, B., van Leeuwen, A., Janssen, J., & Kirschner, P. A. (2021). Mine, ours, and yours: Whose engagement and prior knowledge affects individual achievement from online collaborative learning? *Journal of Computer Assisted Learning, 37*(1), 39-50.

Webb, N. M. (1991). Task-related verbal interaction and mathematics learning in small groups. *Journal for Research in Mathematics Education, 22*(5), 366-389.

Zambrano, J., Kirschner, F., Sweller, J., & Kirschner, P. A. (2019). Effects of prior knowledge on collaborative and individual learning. *Learning and Instruction, 63*, 101214.