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A group-level framework for emergent properties of interactive learning

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Abstract

The purpose of this study was to develop a measurement instrument to examine the underlying latent factors of *collaborative emergence*, a concept that describes how classroom groups function from a complex systems perspective. We examined the underlying factors we discovered in relationship to student engagement and student innovation using bivariate correlations. The study produced three important findings: 1) evidence for a stable two factor solution underlying the concept of collaborative emergence, f1 = complexity and f2 = adaptivity; 2) validity evidence that the group-level factors, complexity and adaptivity, can be situated in a nominological network of well-established engagement variables, and 3) evidence that collaborative emergence has the potential to account for significantly larger amounts of variation in classroom innovation that individual-level cognitive or behavioral constructs.

Key words: collaboration, emergence, innovation, factor analysis

Introduction

Research into the history of collaborative learning shows a transition in focus from the individual-level of analysis to the group-level of analysis (Stahl, et al., 2006). This transition has been marked by an increased interest in complexity thinking in education research (Davis & Sumara, 2006). Complex systems theory suggests group-level patterns emerge from agents interacting together in a system, which Sawyer (2004) refers to as *collaborative emergence* with the context of classroom student groups. Thus, one hallmark of contemporary collaborative learning research is the study of cumulative group-level patterns (as opposed to individual-level variables). The shift in focus from the individual-level of analysis to the group-level of analysis was accompanied, early on, by a call for new tools that can be used to examine the group-level properties of student interaction (Dillenbourg, 1996).

The focus of our recent research (NSF TUES Type I REC-1245081) has been to develop a framework for understanding the group-level properties of interactive learning from a complex systems perspective. We have explored complexity theory in the social and natural sciences and applied the domain general properties of emergence to better understand teamwork in engineering classrooms. We are in the process of developing survey items to assess latent constructs related to collaborative emergence. These items assess student perceptions of their classroom groups, an important topic in engineering education research (Borrego, Karlin, McNair, & Beddoes, 2013). The instrument can be used to determine the relationship between the emergent properties of teamwork and academic outcomes related to classroom learning, instruction, and achievement. The focus for this paper is the relationship between collaborative emergence, student engagement, and student innovation.

Here we share the preliminary outcomes of our assessment instrument development, including evidence for the factor structure of our instrument and other preliminary validity and reliability interpretations. It is important to stress that, along these lines, we share evidence for both our successes and difficulties as our focus is on documenting our preliminary research. However, we present initial multivariate evidence for how latent characteristics of collaborative emergence are related to student engagement and student innovation. Our preliminary results provide evidence for three conclusions: 1) a stable two factor solution underlies the concept of collaborative emergence, f1 = complexity and f2 = adaptivity; 2) evidence for the group-level factors, complexity and adaptivity, can be validated in a nominological network of well-established engagement variables, and 3) group-level variables have the potential to account for significantly larger amount of variation in classroom innovation that individual-level cognitive or behavioral constructs.

Research Concept

Emergence is the process by which patterns percolate from a multiplicity of elements that comprise a complex system. Goldstein (1999) defines emergence as, “the arising of novel and coherent structures, patterns, and properties during the process of self-organization in complex systems” (p. 50). According to his definition, emergence produces a dynamical outcome that surfaces as a complex system evolves. Emergence occurs at the global-level, resulting from the micro-level interaction of elements within a system. In the classroom, interaction among students, where no single participant controls the outcome, produces *collaborative emergence* (Sawyer, 2004). During problem solving emergent group characteristics become evident as students interact and share ideas. Groups may adapt to problem constraints or establish ways of working together.

Collaborative systems like these have a life cycle where many directions are explored, few of which ever lead to success (Audretsch & Feldman, 2003; Krugman, 1991; Nelson & Winter, 1977). What bubbles up out of the brew is considered a random process akin to the survival of the fittest, where the fittest solution is ultimately adopted via benefits outweighing the costs (Frenken, 2006). When a team of student engineers is searching a problem space for improvements, the landscape is comprised of all possible solutions. Random changes made to elements in the problem space by the team ultimately produce an outcome that arises from the process of searching for a solution. Heuristics, or trial and error, are most often used to describe this problem solving process (Nelson & Winter, 1977), and evolution is commonly used as a metaphor to describe which ideas survive the innovation process (Atkinson & Stiglitz, 1969).

For example, imagine a group of engineering students, involved in a solar design project, decide they want to create a solar powered cell phone charger. The group represents a complex system from which an innovative (see definition below) solution will emerge. During the project, they encounter one problem that leads to another and so on. Through trial and error with various ideas, they ultimately decide on a solar powered charger that can be mounted on an RV, which they produce. In this example, the outcome evolved over time out of student manipulation of the problem space and it was unique yet viable enough to be produced. From a macro perspective, the outcome is better characterized by the students’ group process rather than individual acts. While the localized content of the example, the students, solar energy, charging devices, etc. will not apply to other contexts, the interactive characteristics of the process will.

Innovation is a central characteristic of emergent phenomena that survive this type of process, and the notion that a solution is a creative, improved replacement of an old one is central to the innovation process (Winters & Nelson, 1977; Goldstein, 1999). The innovation process is the process by which an old, less effective solution is replaced by a new, creative, more effective one. The creativeness of a solution is generally the assessment of its originality and value to a given community; creative processes that lead to viable technological solutions differentiate innovation from general creativity (Sawyer, 2012). For the purposes of this project, innovation is defined broadly as the pursuit of a creative, imaginative, or inventive solutions during engineering coursework (as opposed to, for example, carrying out a set of laboratory procedures or following directions in a computer learning module).

Instrument Development Overview

The purpose of this project was to develop an instrument to assess the emergent characteristics of student groups in engineering classrooms and examine them in relationship to student engagement and student innovation. Our strategy for developing the items was to develop a conceptual framework that described collaborative emergence based on extant literature, write items to reflect that framework, and then administer them to representative samples of engineering students. We planned three data collections, and examined empirical evidence between each collection to make revisions to the items based on results generated from item analysis and exploratory factor analysis (EFA).

Our initial conceptual framework included four constructs: *multiplicity*, *connectivity*, *adaptivity*, *and spontaneous order*. We hypothesized that these four principles comprised collaborative emergence during teamwork in engineering classrooms. *Multiplicity* was defined as recognition of strengths and weaknesses of group members. *Interconnectivity* was defined as interaction among group members. *Adaptivity* was defined as consideration of competing ideas within the student groups during problem solving. *Spontaneous order* was defined as establishing group cohesion.

We developed items that reflected these four concepts. The items were developed collectively by the project investigators, and vetted by a measurement expert in the learning sciences and engineering faculty members. We then administered them to a sample of engineering students (see below for details about the sampling technique). In our first administration the survey instructions asked students to imagine a time in class they worked in a group. Then, they responded to the items. We analyzed the data using item analysis and exploratory factor analysis. Our interpretation of the results suggested a three factor structure. We used these findings to revise the conceptual framework and rewrite the item set.

In our revisions, we combined *multiplicity* and *interconnectivity* into a single factor we termed *complexity*, which was defined as perception of diverse group composition established through group communication. The other two factors, adaptivity and spontaneous order, remained the same. Given these changes to the conceptual framework, we revised the items accordingly and administered them with the same set of survey procedures (i.e. same target classrooms, different students, same instructions). The empirical evidence used to justify our revisions to the instrument is presented below.

Again, we analyzed the data using item analysis and exploratory factor analysis and interpreted the results. Based on these findings, we decided to test the revised set of items, again, using a priming method. The purpose of using a priming method was to determine if revisions were necessary for the items or for the survey instructions. We considered the possibility that a third factor was not emerging because participants were not thinking deeply enough about their group experiences. For the revised priming method, we asked students to write answers to open ended questions about a past group experience before responding to the items. See Table 1 for a summary of the three data collections.

Table 1

Data collection strategy for item testing

Data Collection	Item set	Survey Method	#Hypoth Factors
Study 1	Set 1 (initial)	No Priming	4 Factor
Study 2	Set 2 (revised)	No Priming	3 Factor
Study 3	Set 2 (revised)	Priming	3 Factor

Note. Item wording and empirical results of item and factor analysis are presented in the results section below.

Method

Sampling and Participants

Students were recruited from engineering courses at two research university campuses. We utilized a stratified sampling technique with classroom and student levels. At the classroom level we purposively targeted courses based on our partnerships with the engineering departments and our experience with conducting online data collections. Because both universities have a focus on energy technologies, we targeted common engineering courses that develop competence in these areas for instrument development and matched them between universities. Access to the courses provided adequate variation and sample size to examine the psychometric properties of the instrument. Samples were taken from the courses listed in Table 2.

Table 2

Courses targeted for recruiting survey participants

Research University #1	#	Research University #2	#
Engineering Mechanics I	155	Engineering Mechanics	140
Dynamics of Rigid Bodies	105	Solid Mechanics	225
Fluid Mechanics	70	Structural Mechanics	120
Thermodynamics	60	Thermofluids I	150
Heat Transfer	55	Principles Mechanical Design	136
Energy Science Laboratory	36	Energy Systems Design	17
Intermediate Thermodynamics	35	Thermofluids II	90
Applied Combustion	20	Computational Fluid Dynamics	75
Renewable Energy	30	Renewable Energy Engineering	50
Possible Recruitment Pool:	566	Possible Recruitment Pool:	1003

Note. Table represents all possible courses with combined sections yielding student totals in rows. Not all course sections were sampled for any data collection.

At the student level, we collected convenience samples from the target list of courses. Researchers visited target courses (with instructor permission) and offered students the opportunity to respond to the online survey. A link to the survey was provided to them via their course learning management system or email, depending upon the instructors' preference. Students were paid ten dollars for completing the survey. The incentive was transferred to their student ID cards after completion was ensured. The survey took roughly twenty minutes to complete. We analyzed the raw data for completion time as well as included an "honesty" check question to verify the accuracy of the survey. Students who did not answer the honesty check question correctly, or who completed the survey faster than 580 words per minute were removed from the data sets.

**Note. Complete demographic information for the three samples is currently being obtained from the university registrars' office. Students provided their student ID's before completing the survey. These ID's are being used to access their demographic information. This information will be included for all three samples here before the final submission.*

Measures

Collaborative Emergence Scale – The collaborative emergence scale is the instrument under development in the current project. The items were developed to examine student perceptions of their classroom working groups from an emergent systems perspective. We have developed two iterations of the scale. For our first iteration, we developed a set of items to reflect our four hypothesized underlying dimensions of collaborative emergence: multiplicity, connectivity, adaptivity, and spontaneous order. We revised the scale according to our initial results, rewriting many of the items and refining the hypothesis to include three factors: complexity, adaptivity, and spontaneous order. See the results section for the wording of the items. Items were measures on a seven point likert scale with two anchors, "not accurate" to "very accurate"

Classroom Engagement Scale – The classroom engagement scale (Wang, Bergin, & Bergin, 2014) is a multi-dimensional measure of individual-level classroom engagement that contains 24 items. We examined three underlying factors from the scale: Affective Engagement (5 Items; Time 1 $\alpha = .91$, $n = 347$; Time 2 $\alpha = .91$, $n = 238$; Time 3 $\alpha = .88$, $n = 83$), Behavioral Engagement-Effortful Class Participation (5 items; Time 1, $\alpha = .75$, $n = 347$; Time 2 $\alpha = .79$, $n = 238$; Time 3 $\alpha = .71$, $n = 83$), and Cognitive Engagement (8 items, Time 1 $\alpha = .80$, $n = 347$; Time 2 $\alpha = .84$, $n = 238$; Time 3 $\alpha = .88$, $n = 83$). An example affective engagement item read, "I feel excited." An example behavioral engagement item read, "I get really involved in classroom activities." An example cognitive engagement item read, "I judge the quality of my ideas or work during class activities." Items were measures on a seven point likert scale with two anchors, "never" to "almost always."

Classroom Innovation Scale – The innovation scale contains four items written to assess student perceptions that they are engaged in innovative classroom activity. (4 items; Time 1 $\alpha = .85$, $n = 347$) (Time 2 $\alpha = .86$, $n = 238$) (Time 3 $\alpha = .84$, $n = 83$). The four items were, "We used our imaginations," "We explored innovative ideas," "We focused on creative answers," "We tried to invent new things." Items analysis of items, conducted over three administrations of the items produced evidence of internal reliability. Items were measures on a seven point likert scale with two anchors, "not accurate" to "very accurate"

Analysis

The data were examined using IBM SPSS v21. Before the formal statistical analyses were conducted, we examined descriptive statistics for our proposed collaborative emergence items. Examination of the statistics, in all three data collections, produced evidence for univariate normality. This evidence, in conjunction with our sampling techniques, suggested assumptions for our planned statistical tests had not been violated.

The dimensionality of our collaborative emergence items was analyzed using maximum likelihood factor analysis (see Green & Salkind, 2011 for procedures). We used principle axis extraction with a direct oblimin rotation as this is the most appropriate for likert scale data with oblique factors (Tabachnik & Fidell, 2007). Three criteria were used to determine the number of factors to rotate: our a priori hypothesis about the number of underlying factors, the scree test, and the interpretability of the factor solution.

Based on our interpretation of the exploratory factor analysis results, we extracted the most interpretable factor solution from each of the data sets, and examined the factors in relationship to our measures of classroom engagement and student innovation by calculating bivariate pearson product moment correlations.

Results Study 1

Our initial framework consisted of sixteen items representing four concepts: multiplicity, connectivity, adaptivity, and spontaneous order. The scree plot indicated that our a priori four factor hypothesis was incorrect. Based on the plot, two factors were rotated using a direct oblimin procedure with Kaiser normalization. The rotated solution, presented in Table 3 along with item wording, yielded two interpretable factors: f1 = complexity; f2 = adaptivity. The complexity factor (Eigenvalue = 9.66) accounted for 60.43% of the item variance and the adaptivity factor (Eigenvalue = .96) accounted for 5.90% of the total variance. Descriptive statistics and bivariate correlations were then calculated for all study variables. See Table 4 for a summary of results.

Table 3

Conceptual Framework, Items, and Dimensionality of Initial Scale

Conceptual Framework		Items	Loadings	
Multiplicity			F1	F2
1	different abilities	There was a mix of students with different abilities	*	0.49
2	contributed ideas	Each group member contributed something unique	0.72	*
3	contributed work	All members contributed something different to the work	0.66	*
4	different perspectives	Each member provided a different perspective	0.46	*
Interconnectivity				

5	interacted w each other	Everyone interacted with everyone else	0.85	*
6	worked w each other	Everyone worked with everyone else	0.94	*
7	communicated (digital)	Members were electronically connected with each other	0.42	*
8	communication	There was communication among group members	0.84	*
Spontaneous Order				
9	working system	We established a system for working together	0.76	*
10	cooperation	We cooperated with each other	0.90	*
11	organization	We organized ourselves	0.46	*
12	arrangement	We arranged a way to work together	0.60	*
Adaptivity				
13	evolving ideas	Ideas evolved as the group spent time together	*	0.62
14	unexpected challenges	We encountered unexpected challenges	*	0.54
15	changes in direction	We changed direction a number of times	*	0.63
16	considering possibilities	We considered lots of possibilities	*	0.63

Note. * = loadings < .40 suppressed to improve visualization. n = 347. Loadings generated using EFA with principal axis extraction and direct oblimin rotation. Pattern matrix is presented. F1 = Complexity; F2 = Adaptivity

Table 4

Descriptive statistics and bivariate correlations among study variables (study 1)

	Descriptive Statistics				Bivariate Correlations				
	Min	Max	Skew	Kurt	1	2	3	4	5
1. Complexity	-3.07	1.63	-0.76	0.53					
2. Adaptivity	-3.45	1.92	-0.67	0.72	.880**				
3. Aff Engage	-2.62	1.67	-0.41	-0.39	.221**	.235**			
4. Beh Engage	-2.85	1.97	-0.21	-0.24	.411**	.416**	.570**		
5. Cog Engage	-3.24	1.92	-0.25	-0.20	.330**	.312**	.571**	.642**	
6. Innovation	-2.25	2.11	-0.24	-0.21	.509**	.614**	.361**	.367**	.314**

Note. Descriptive statistics are based on standardized variables (m = 0; sd = 1). ** = a < .01 (two tailed). n = 347

Although the factor structure was theoretically interpretable, conceptually it seemed reasonable that students should be able to distinguish a third factor among the items. This issue is addressed further in the discussion. However, essentially we hypothesized that the conflation of the spontaneous order items with the complexity items was perhaps due to the wording of the items themselves, rather than the student's inability to distinguish between the group characteristics we were trying to measure. Thus we rewrote the items, re-administered the survey, and reanalyzed the factor structure of the data.

Results Study 2

Our revised framework consisted of eighteen items representing three concepts: complexity, adaptivity, and spontaneous order. The scree plot indicated that our a priori three factor hypothesis was incorrect. Based on the plot, two factors were again rotated using a direct oblimin procedure with Kaiser normalization. The rotated solution, presented in Table 5 along with item wording, yielded two interpretable factors: f1 = complexity; f2 = adaptivity. The complexity factor (Eigenvalue = 11.45) accounted for 63.61% of the item variance and the adaptivity factor (Eigenvalue = 1.02) accounted for 5.7% of the total variance. Descriptive statistics and bivariate correlations were then calculated for all study variables. See Table 6 for a summary of results.

Table 5

Conceptual Framework, Items, and Dimensionality of Revised Scale

Dimensions		Item	Loadings	
Complexity			F1	F2
1	Strengths	Students in my group had different strengths	0.75	
2	Experience	All members brought their own experiences to the group	0.87	
3	Perspective	Each member's individual perspective influenced the group	0.56	
4	Contribution	Each group member contributed something unique	0.58	
5	Interaction	Everyone interacted with everyone else	0.75	
6	Communication	There was communication among group members	0.93	
Spontaneous Order				
7	Working system	Over time we established a system for working together	0.78	
8	Collaborating	We began to collaborate with each other more and more	0.73	
9	Organized behavior	We became increasingly organized as we worked together	0.83	
10	Trust/predictability	Group members began to rely on each other	0.43	
11	Achieving consensus	We built consensus in our group over time	0.51	
12	Compromise/forgiveness	We became more willing to compromise with each other		0.74
Adaptivity				
13	Evolving Ideas	Ideas evolved as my group worked together	0.46	0.44
14	Unexpected challenges	The group explored potential drawbacks to different ideas		0.85
15	Change in direction	We imagined many different directions the group could take		0.77
16	Possibilities	As we worked together, we considered lots of possibilities		0.66
17	Problem constraints	The group took problem constraints into account		0.51
18	Competing solutions	The group discussed a number of competing ideas		0.89

Note. * = loadings < .40 suppressed to improve visualization. n = 238. Loadings generated using EFA with principal axis extraction and direct oblimin rotation. Pattern matrix is presented. F1 = Complexity; F2 = Adaptivity

Table 6

Descriptive statistics and bivariate correlations among study variables (study 2)

	Descriptive Statistics				Bivariate Correlations				
	Min	Max	Skew	Kurt	1	2	3	4	5
1. Complexity	-2.93	2.22	-0.43	0.99					
2. Adaptivity	-2.92	2.35	-0.73	1.49	.872**				
3. Aff Engage	-2.50	2.37	0.10	-0.17	.253**	.266**			
4. Beh Engage	-3.10	1.88	-0.33	-0.02	.252**	.252**	.576**		
5. Cog Engage	-2.64	1.69	-0.41	-0.17	.140*	.173**	.586**	.605**	
6. Innovation	-2.45	2.37	-0.40	0.54	.589**	.761**	.299**	.209**	.214**

Note. Descriptive statistics are based on standardized variables (m = 0; sd = 1). ** = a < .01 (two tailed). n = 238

Results Study 3

Based on the results of our second administration of the scale, we wanted to determine if students cannot distinguish between complexity and spontaneous order, because cognitively it is difficult to distinguish, or if asking them to generate a more detailed account of a particular experience before completing the items generated a more nuanced factor structure. Thus, we surveyed a third convenient sample of undergraduate students from the same set of courses and asked them to write responses to open ended questions about a collaborative experience. Then, we asked them to respond to the same item set from the second administration. The priming questions were as follows:

1. In a few sentences, provide a brief description of the project. What was the assignment? How were the groups formed? How long did it take to complete? What was it, ultimately, that you accomplished together?

2. Without providing any personally identifying information, describe the composition of your group. Was there a diverse group of students? Did different students have different strengths? Was the work distributed evenly among members? Did students work well together? Please provide any important details.

3. In a few sentences, describe how your group decided to complete the assignment. Did the group engage in brainstorming? Were there lots of ideas being offered up as possibilities? Did the group consider opposing views? Was there discussion about the best way to proceed?

4. Finally, describe how your group organized the work. How did you work together to find a way to complete the assignment? Did you rely on each other for different things? Were all group members treated fairly? Please provide any important details.

Our framework consisted of the same eighteen items from study 2 representing three concepts: complexity, adaptivity, and spontaneous order. The scree plot indicated that our hypothesized three factor solution was incorrect. Based on the plot, two factors were again rotated using a direct oblimin procedure with Kaiser normalization. The rotated solution again yielded two interpretable factors: F1 = complexity; F2 = adaptivity. The complexity factor (Eigenvalue = 10.45) accounted for 58.01% of the item variance and the adaptivity factor (Eigenvalue = 1.44) accounted for 8.1% of the total variance. Descriptive statistics and bivariate correlations were then calculated for all study variables. See Table 6 for a summary of results.

Table 7

Conceptual Framework, Items, and Dimensionality of Revised Scale

Dimensions		Item	Loadings	
Complexity			F1	F2
1	Strengths	Students in my group had different strengths	0.75	

2	Experience	All members brought their own experiences to the group	0.85	
3	Perspective	Each member's individual perspective influenced the group	0.84	
4	Contribution	Each group member contributed something unique	0.91	
5	Interaction	Everyone interacted with everyone else	0.76	
6	Communication	There was communication among group members	0.90	
Spontaneous Order				
7	Working system	Over time we established a system for working together	0.71	
8	Collaborating	We began to collaborate with each other more and more	0.76	
9	Organized behavior	We became increasingly organized as we worked together	0.75	
10	Trust/predictability	Group members began to rely on each other	0.76	
11	Achieving consensus	We built consensus in our group over time	0.82	
12	Compromise/forgiveness	We became more willing to compromise with each other	0.75	
Adaptivity				
13	Evolving Ideas	Ideas evolved as my group worked together	0.70	
14	Unexpected challenges	The group explored potential drawbacks to different ideas		0.57
15	Change in direction	We imagined many different directions the group could take		0.62
16	Possibilities	As we worked together, we considered lots of possibilities		0.66
17	Problem constraints	The group took problem constraints into account	0.52	
18	Competing solutions	The group discussed a number of competing ideas		0.94

Note. * = loadings < .40 suppressed to improve visualization. n = 83. Loadings generated using EFA with principal axis extraction and direct oblimin rotation. Pattern matrix is presented. F1 = Complexity; F2 = Adaptivity

Table 8

Descriptive statistics and bivariate correlations among study variables (study 3)

	Descriptive Statistics				Bivariate Correlations				
	Min	Max	Skew	Kurt	1	2	3	4	5
1. Complexity	-3.31	1.25	-1.53	2.10					
2. Adaptivity	-2.66	1.50	-0.76	0.11	.658**				
3. Aff Engage	-3.38	1.63	-0.75	0.71	.488**	.340**			
4. Beh Engage	-3.21	1.70	-0.92	0.78	.620**	.503**	.682**		
5. Cog Engage	-4.71	1.61	-1.50	5.12	.236*	0.18	.595**	.597**	
6. Innovation	-2.91	1.46	-0.99	1.14	.653**	.663**	.361**	.560**	0.17

Note. Descriptive statistics are based on standardized variables (m = 0; sd = 1). ** = a < .01 (two tailed). n = 83

Discussion

Contrary to our hypothesis, the combined results of our exploratory factor analyses suggest a two factor solution to our collaborative emergence items. Independent interpretations of the eigenvalues, scree plot, and factor loadings revealed a stable pattern of results across the three data collections. These factors were interpreted as 1) complexity and 2) adaptivity, respectively.

Our findings are supported by evidence from studies of social affordance in learning environments (i.e. Gaver, 1996). Psychological research in collaboration suggests that students attend to both the sociability (i.e. emotional support) and functionality (task specific support) of their collaborative learning environments (e.g. Kreijns, Krischner, Jochems, & van Buuren, 2005) during interaction.

The findings from the current study suggest that, from a systems perspective, students experience their face-to-face classroom groups as complex (diverse and interconnected) and adaptive (exploring competing ideas to solve problems). One unexpected finding from our work suggests that students don't appear to differentiate between group multiplicity and group spontaneous order.

Surprisingly, a single dimension seems to underlie the items written to represent these two latent constructs, often described in the complex systems literature in both the humanities (Davis & Sumara, 2005) social (Sawyer, 2004a) and natural sciences (Mitchell, 2009). Even our priming test, meant to cognitively facilitate deep thought about the nuances of group interaction, did not lead to increased discrimination among these items, instead further distinguishing between the two factor solution.

This finding leads us to believe that perhaps the perception of multiplicity is intertwined with attaining spontaneous order. In other words students do not distinguish between the process of learning about each other's perspectives and establishing a working order or attaining synergy. Clearly, additional replications of the factor structure are required, as well as continued examination of the qualitative data we have collected.

That being said, our current findings provide important results about the differential impact of individual-level engagement vs. group-level interaction on classroom innovation. Correlation coefficients between collaborative emergence and classroom innovation were roughly double those between individual-level classroom engagement and classroom innovation – a finding that was consistent across all three studies.

This is an important preliminary finding because it suggests that group-level, emergent phenomena are an important predictor of academic outcomes. Researchers have recently produced evidence for collective intelligence during group problem solving tasks (Woolley, Chabris, Pentland, Hashmi, & Malone, 2010). Emergent variables may be an important component of group "g", which findings suggest is facilitated by theory of mind and other psychological processes likely related to environmental affordances (Engle, Woolley, Jing, Chabris, & Malone, 2014), whether online or in person.

Taken together, our current results suggest students perceive their classroom working groups as complex and adaptive, and that these group-level qualities can be validated in a nominological network of well-established engagement variables. Results also suggest that group-level variables have the potential to account for significantly larger amounts of variation in classroom innovation than individual-level cognitive or behavioral constructs commonly reported on in the educational and psychological literature.

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