Using Innovation with Contrasting Cases to Scaffold Collaborative Learning and Transfer

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Abstract: The current study examined dyadic interaction and transfer resulting from a math lesson presented in traditional lecture-then-practice fashion versus in innovation then efficiency fashion (Schwartz, Bransford, & Sears, 2005). While dyads in the Traditional condition were able to solve the practice problems, only one out of 18 individuals successfully solved a difficult transfer problem on the posttest. By contrast, a clear pattern of steps in the problem solving process of the Innovation dyads showed that most students could perceive and verbalize the correct solution to the practice problems (7 of 9 dyads) but had trouble translating their insights into a mathematical solution. Only three Innovation dyads successfully translated their perceptions into correct mathematical formulations—suggesting an area for further scaffolding in future work. However, five of these six individuals correctly solved the difficult posttest transfer problem. The use of contrasting cases during innovation appeared instrumental to participants’ perception and formulation of correct solutions.

There is a general consensus that collaborative learning leads to better academic outcomes than individual learning, at least under certain conditions (e.g., Cohen, 1994; Johnson, Johnson, & Stanne, 2000; O’Donnell, 2006; Slavin, 1996). A primary benefit of learning in groups is that students can learn from other students by exchanging ideas, recognizing and reconciling different perspectives, and by co-constructing and practicing problem-solutions (Barron, 2003; Stacey, 1999; Webb, Troper, & Fall, 1995). However, merely putting students in groups does not guarantee effective collaborative learning. For example, Barron (2003), in a conversation analysis of high achieving 6th grader triads’ problem solving, found that some groups showed such disjointed interactions that the individuals in those groups would have likely performed better working alone. The less successful groups tended to ignore or reject correct proposals and failed to connect correct proposals to preceding conversational topics.

Many studies of learning in small groups suggest that advantages can be obtained when certain scaffolds are used. Slavin (1983, 1996) has argued for group goals (or group rewards) and individual accountability as a critical motivating factor. Imposing scripts or specific roles is also a way to increase successful group learning outcomes (O’Donnell & Dansereau, 1992). Training students for cooperation is also beneficial because cooperative learning requires different forms of behavior that students might not experience in typical classrooms (Cohen, 1994). From a nine-month study and a two-year follow-up study of junior high school students, Gillies (2002, 2003) concluded that students who worked in small groups in a structured way consistently benefitted more—in terms of the quality of group work, enjoyableness, and social cohesion—than students who were in unstructured groups that were not trained to collaborate.

Generally, scaffolds such as reward-systems, scripts, and group training are intended to promote behaviors that support learning, such as generating hypotheses and explanations (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Koenig & Griggs, 2004; Webb et al., 1995). Interaction factors within a group are important for successful group outcomes (Dillenbourg, 1999; Dillenbourg, Järvelä, & Fischer, 2009). Barron (2000) identified three interaction features for successful collaborative learning—sharing task alignment, joint attention, and mutuality. Others have noted the importance of frequent task-related talk, wrestling with a task together, and explicit correspondence to a partner’s work (Cohen, 1994; Vedder, 1985). In the two-year qualitative study of Asian college students’ experiences in collaborative problem-based-learning classrooms, Remedios, Clarke and Hawthorne (2008) reported that although the Asian students tended not to speak frequently, probably due to language barriers and cultural differences, they tended to listen more, and when prompted by tutors or members, they were successful in task completion and sharing learning with peers. In other words, the quality of the interaction appears to be at least as important as the quantity for productive learning outcomes.

Although the literature has constantly proposed scaffolding for better outcomes of collaborative learning, it is uncertain whether research-tested scaffolds are implemented effectively, if at all, in many classrooms. Antil, Jenkins, Wayne, and Vadasy’s (1998) survey of elementary school teachers revealed that although many teachers used collaborative learning in their classrooms, most of them used it without specific forms or were missing certain scaffolds. This suggests a need for research that identifies what types of tasks may be productive for collaboration without requiring extensive scaffolds. This approach could be an efficient way to foster the benefits of collaborative learning because task features may be relatively easy for teachers or curriculum designers to prepare and manipulate. Students’ interaction and willingness to collaborate are influenced by the nature of the task (Bennet & Dune, 1991; Cohen, 1994; O’Donnell & Dansereau, 1992).
Simple tasks do not tend to benefit from unstructured collaborative learning (Cohen, 1994; Phelps & Damon, 1989). Cohen (1994) argued that collaborative tasks needed to be complex enough to prevent a single member from being able to solve the task without contributions from teammates.

Recent evidence points to the potential of complex and innovation-oriented tasks to be productive for collaborative groups (Kapur, 2010; Kapur & Kinzer, 2009; Laughlin, Hatch, Silver, & Boh, 2006). Presumably, given complex problems, students find that they are not able to solve them alone, so they are naturally motivated to work together. Kapur and Kinzer (2009) and Kapur (2010) found benefits of complex and ill-structured tasks for collaborative groups learning mathematical and science concepts. Although groups in the complex and ill-structured conditions struggled and even failed to solve the problems, they significantly outperformed the lecture-and-practice groups on a posttest that included near and far transfer measures. Kapur and Kinzer (2009) argued that there might be “a hidden efficacy about learner-generated processes” (p. 38) during the collaborative learning context. Kapur (2010) suggested that failure experiences during learner-generated processes can be productive for deeper understanding (i.e., productive failure).

The Innovation and Efficiency framework of Schwartz, Bransford, and Sears (2005) describes two complementary approaches to instruction that highlight potential benefits of productive failure for preparing students to learn from a subsequent lesson. Innovation emphasizes generation of solutions by students. Efficiency emphasizes traditional lesson-then-practice processes. Innovation has similarities with the concept of productive failure because when students engage in Innovation activities they are not expected to invent an expert formulation; instead, the experience is meant to help them notice and differentiate key features that a subsequent Efficiency activity can further organize, thereby better preparing students for future transfer. One possible mechanism by which Innovation tasks may help students prepare for future learning is by presenting them with opportunities to wrestle with contrasting cases that emphasize the central concepts of interest (Marton, 2008; Schwartz & Bransford, 1998; Schwartz, Sears, & Chang, 2007).

While previous work has suggested ways in which innovation-oriented productive failure experiences may benefit students learning collaboratively, further study is needed to determine whether these instructional practices function as hypothesized—helping students notice key factors and thereby preparing them to understand expert solutions more deeply. The current study builds upon a previous quantitative investigation of the Innovation and Efficiency framework for its ability to characterize naturally productive collaborative tasks (Sears, 2006). It examines dyadic interactions in an Innovation condition versus a Traditional lesson-then-practice condition in an effort to explain how Innovation activity better prepared participants for subsequent individual transfer.

Methods

Participants
University students (N = 76) with little or no background in statistics – those who took no more than A/P or introductory courses – were recruited through email lists and campus flyers. Forty participants worked individually and 36 worked collaboratively in same-sex dyads. They were randomly assigned to the Innovation and Efficiency condition or the Traditional lesson-then-practice condition. This study focuses on the dyads because they permit an analysis of group interactions. Nine dyads (6 female, 3 male) participated in each condition.

Materials
A learning packet, posttest, and transcription of videotaped interactions comprised the materials for the study (for more details on the materials see Sears, 2006). The learning packet consisted of nine pages of lessons and practice problems on the chi-square formula. The only difference in the materials used in each condition was the order in which they were completed. The Traditional condition read a lesson, then solved practice problems, then worked through a final example (with solution provided). The Innovation condition attempted to solve the practice problems first, then read the lesson, and received the final example.

The practice problems used contrasting cases—a feature that was expected to benefit participants in the Innovation condition by helping them notice key variables and scaffold their mathematical thinking. For example, the first set of practice problems required participants to differentiate three dice according to “fairness.” The results of a number of rolls for each of the three dice were provided and students had to construct a formula that would differentiate each die from least fair to most fair. The expert solution to this problem involves calculating the chi-square statistic: summing the squared differences between observed and expected values over the expected value. Because Traditional participants would have already seen this formula, they were expected to attend to the computational accuracy rather than comparing across the dice for solution insights. The Innovation participants were not expected to invent the chi-square formula, but they were expected to notice that one case was obviously least fair (because one side of the die appeared on 40% of the rolls). The other cases were harder to differentiate because each side of the dice appeared nearly equally often.

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The posttest consisted of calculation and comprehension problems and one target transfer problem designed in preparation for future learning (PFL) fashion (Bransford & Schwartz, 1999). The target transfer problem required participants to adapt their understanding of the chi-square formula to invent a measure of inter-rater reliability similar to Cohen’s kappa. To help participants do this, a resource problem was presented earlier in the posttest that showed an inter-rater reliability matrix and gave suggestions for what to calculate. To succeed on the target transfer question, participants needed to complete a double-transfer: adapting the chi-square formula they learned during the lessons to work with the inter-rater reliability problem learned in the resource problem. The correct solution involved performing a chi-square calculation on just the agreement cells of the reliability matrix (rather than all of the cells, which would yield a nonsensical answer). This double-transfer was expected to be very difficult for participants, but it provided an indicator of which condition better prepared students to learn from further instruction (i.e., the resource problem) and transfer their knowledge to new and challenging problems.

**Procedures**

Participants spent 35 to 65 minutes going through the learning packet. Those in the Innovation condition attempted to invent solutions to the practice problems before receiving the lesson and final example while those in the Traditional condition received the lesson, then the practice problems, and then the final example. Following a 5-minute break, participants completed the posttest (approx. 25 minutes).

**Results**

Regarding quantitative results previously reported by Sears (2006), the Innovation condition did not take longer than the Traditional condition during the learning or test phases, and they performed similarly on the calculation and comprehension problems. The key outcome of interest here is the analysis of dyadic interaction that may explain the advantage shown by the Innovation dyads on the difficult target transfer problem. Only 1 of 18 participants in the Traditional dyad condition successfully completed the double-transfer problem; 5 of 18 participants in the Innovation dyad condition did so (more than all other conditions combined).

Sample interactions from dyads in each condition are presented followed by a description of the coding scheme and results. As shown in the following interactions, dyads in the Innovation condition tended to compare across the contrasting cases to estimate which of the three dice should be ranked least, most, or somewhat fair. Next they attempted to formalize their estimated rankings by developing a mathematical formula (as required by the problem). Most dyads showed accurate perceptions of the problem and many made progress on the mathematical formulation. However, only a third of the dyads invented a near-expert formula that successfully differentiated the three cases.

**Dyad 1 (Innovation Condition):** Noticing the conspicuous (least-fair) case and conjecturing the expected value as a way to compare the remaining two cases. They eventually succeeded in differentiating the cases verbally and mathematically.

A: Yeah this (Case 2) one seems like the least fair.
B: Least fair, exactly.
A: And these two (Case 1 and Case 3) seem harder to tell.
B: They seem the same to me. Are we supposed to circle these? So, if they’re equal, do we just rank them most fair together?
A: Alright, let’s just start with this one (Case 2) being the least fair.
B: You seem to know what’s going on. Let me see this. (laughing)
A: So, for each number we should get 5 for this (Case 1 and Case 2) one and ten for this (Case 3) one. And each of them (each side of the die in Case 1) for this one should get five.
B: Each of them, right?

Dyad 1 noticed that case 2 looked the least fair (one of the numbers appeared on 40% of the rolls). Then, they tried to differentiate the similar two cases mathematically. First, they found the number of rolls that should appear for each side if the dice were fair (i.e., the expected value). This is a notable point because the expected value was not provided in the problem. We suspect that by inventing that variable, these students were more prepared to understand how it worked in the chi-square formula, the canonical solution that was taught in the lesson. Both participants in this dyad successfully solved the target transfer problem on the posttest (taken individually).
Dyad 16 (Innovation Condition): Noticing that the two challenging cases show a similar difference between the observed and expected values but one case has twice as many rolls as the other. They succeeded in differentiating the cases verbally and mathematically.

C: Let’s see. What if we say like the number these (Number of rolls in Case 1) should be is 5, the difference of each of these 5-5, 6-5 ah 4-5, 6-5 and then 4-5 equals -1. And then, how do we do this one?

D: So...

C: Let’s see. What if we say like the number these (Number of rolls in Case 1) should be is 5, the difference of each of these 5-5, 6-5 ah 4-5, 6-5 and then 4-5 equals -1. And then, how do we do this one?

D: So...

C: Ok. And then... So these numbers (Number of rolls in Case 3) distribute the same way right? They are all have 2 on them, 2 -1s, but this (Case 3) is probably more fair than this (Case 2).

D: Because it’s (Case 3) rolled a higher number of times?

C: Right, right. It’s like a better study right?

D: So...

C: We don’t know how to do that in terms of numbers. He he he he!

Experimenter: Just try to invent one. It doesn’t have to be perfect.

D: I mean I guess you could average them, right?

C: If you average them, these (Case 1 and Case 3) are both going to come out the same, right? So then because adding them up could get 0, so if you was it like squaring it?

D: To make it positive?

C: Yeah if you square this (Each of E-O).

D: That’s still the same number.

C: And then divide it by...

D: The number of times rolled?

C: Yeah. Will that work? Cause if we squared it (each cell of Case 3) 1, 4. If we square this it’s 4 but if we divide it by 50...

D: 50 then by 25.

C: By 25. Then if we did it with this we have to do the same thing right?

D: Yeah, this one is .08. (Case 3)

C: 4/50?

D: Uhnum. 1.28 (Case 2), 0.16 (Case 1)

C: Ok, so the smaller the number, the more fair. He he he he.

D: Yeah, might as well be.

Group 16 shows a good example of how the students co-constructed a solution that differentiated all three cases, even the two most similar cases. After getting the expected value, this group subtracted the expected value from the observed values and summed them to see how much each case differed from expected. They found that case 1 and 3 yielded the same Σ(O-E) value. The contrasting cases were designed to be tied by this approach in order to block this incomplete solution and push for considering another operation (i.e., dividing by N or E). Noticing the tie, the participants thought that case 3 should be more fair than case 1 because it was rolled more times. After struggling for a moment, they eventually thought of squaring the (O-E) to avoid negative values. Seeing that this still produced a tie, the partners co-constructed the idea of dividing by the number of rolls (N). This was considered an ideal solution to the difficult contrasting cases. One of the participants in this dyad correctly solved the target transfer posttest problem.

Almost all groups in the Traditional condition went through the numerical solutions smoothly. Their activities showed considerable focus on calculations and error checking. They tended to plug in numbers into the formula they saw in the Lesson page right away. Examples from Dyads 2 and 5 are shown below.

Dyad 2 (Traditional Condition): Getting the numbers for each component of the formula (E, E-O, +E).

E: Ok... so um... for each one (cell) E should be 1/5th, right?

F: Yeah.

E: Then 1/5th of the number times, so 5 for the first 2 cases and 10 for the third case. So do you want to just write it off?

F: Yeah, I just completely forgot the chi square formula.

E: Ok so chi square = e-o squared over e. So for case 1 and 2 e = 5, e=5 then e=10. Then we just add up the 5-5 squared.

E: 5-6 squared over 5, 5-4 squared over 5. Like that so, um... so this (Number “5” in the cell) one’s gonna be 0 because 5-5 is 0 but um... So all these are going to be 1/5.
F: 1/5 1/5 1/5 so chi square for this is going to be 4/5ths. Right?
E: Right.

Dyad 5 (Traditional Condition): Plugging in numbers and checking calculations.
G: Ok why don’t you plug them in?
H: Ok so it was sum of expected - observed squared over expected. So for the first one we had...um it was rolled 25 times so like this is the first side so um...

G: For this one its also 5 sided we rolled it. Does it matter that this (Case 1 and Case 2) is rolled 25 and this (Case 3) is rolled 50?
H: I think it’s just gonna give us a different fraction.
G: Alright. Ok. So then, this (Case 1) one we expect each one of these (Number of rolls) to be 5, um so again this (Case 2) is 5 sided. So this is 1/5 and 1/5 ok, this one is 2 squared is 4/5 that’s 4/5ths. Did I do that right?
H: Uhum.
G: And this is also what... oh no sorry that wasn’t 2 that was 5 (Case 2) ok yeah so this is um so yeah, this is 10-5 no 5-10. Um yah so that’s 5 squared 25/5 so 5. Ok and then for this one this is 2.
H: 4/5 and then 1/5 again?
G: Ok 2/5 3/5 7/5 and 5 7/5 is...
H: 6 and 2/5.
G: 6 and 2/5.
H: So this (Case 3) most fair ok. This is least fair (Case 2) this is somewhat fair (Case 1).

Although the Traditional condition appeared to push for a focus on computational accuracy, it did not prevent participants from asking important questions, such as, “does it matter that this is rolled 25 and this is rolled 50 [times]?” (Dyad 5). However, as suggested by the partner’s response, it also did not necessitate developing answers to those questions that would yield insight into why the chi-square formula operated as it did.

The subsequent results show the results of the coded transcripts across all 18 dyads. Table 1 shows the coding scheme. The codes are numbered to suggest a sequence by which Innovation dyads might proceed through the problem—noticing key features first and then formalizing their understanding mathematically in increasingly complex (and accurate) ways.

Table 1: Coding scheme for dyadic interactions.

<table>
<thead>
<tr>
<th>Coding Goals</th>
<th>Code</th>
<th>Examples of quotes that earned credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st goal</td>
<td>1. Case 2 is least fair.</td>
<td>1 – “This one (case 2) is definitely least fair” – dyad #9</td>
</tr>
<tr>
<td>Perceptual Ranking – Rank the three cases correctly without numerical solution</td>
<td>2. Case 1 and Case 3 are hard to differentiate (e.g., they show the same range; tied according to ( \sum (E-O) )).</td>
<td>1 – “I was thinking like this (Case 3) deviates from 10 by 1 and this by 1 this by 1 total of 4 deviations … this one (Case1) has 4 too” – dyad #11</td>
</tr>
<tr>
<td>3. Case 3 has more rolls (50 vs. 25) and make a judgment.</td>
<td>1 – “This one’s 25 (Case 1) and this one’s 50 (Case 3)” – dyad #1</td>
<td></td>
</tr>
<tr>
<td>2nd goal</td>
<td>4. Find E (the expected value)</td>
<td>1 – “1/5th of the number times [total number of rolls], so 5 for the first 2 cases and 10 for the third case” – dyad #2</td>
</tr>
<tr>
<td>Numerical Solution – Provide a single value for each case that can uniquely rank them</td>
<td>5. (E-O) and/or (E-O)^2</td>
<td>1 – “It's going to be 5 minus 5 is zero squared over 5 is zero.” – dyad #17</td>
</tr>
<tr>
<td>6. ( \div N ) OR ( \div E ) to differentiate cases</td>
<td>1 – “so (5-6) squared over 5 so that 1/5” – dyad #18</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows the results of the coding scheme for each condition. It also shows performance on the target transfer problem. Five of the 18 individuals in the Innovation dyad condition succeeded on the target transfer posttest problem versus only one of 18 individuals in Traditional dyads. Importantly, all five of those Innovation individuals worked in dyads that received credit on every code. Put another way, only one individual in the Innovation dyads that succeeded on the practice problems failed to successfully complete the double-transfer problem on the posttest. Thus, the learning activity, when done in Innovation fashion, was
diagnostic of participants’ level of understanding. Only those students who both perceived the key features of the problem and translated them into a mathematical operation successfully answered the target transfer posttest question.

In addition, it is apparent from the decrease of success between code 4 and code 5 from seven out of the nine dyads to only four that many Innovation dyads struggled to translate their perceptions into mathematical operations. This finding could be valuable to educators because it suggests moments at which teacher scaffolding could be most effective, not just for initial success but potentially for subsequent individual transfer as well.

In contrast to the Innovation condition, the results for the Traditional condition appeared neither successful nor diagnostic. Only one of 18 participants in the Traditional dyad condition succeeded on the target transfer posttest problem. However, nearly every dyad calculated the chi-square statistic on the practice problems. Thus, the practice problems not only failed to differentiate students with deep understanding from those needing additional support, they failed to prepare students to transfer their knowledge. This is not to say that lesson-then-practice instructional methods cannot facilitate deep understanding and transfer. We suspect, instead, that until a problem requires students to compare across cases to make sense of how a formula works, they may fail to do so.

Table 2: Number of dyads that got credit for each coding element, and number of those individuals who succeeded on the target transfer problem.

<table>
<thead>
<tr>
<th>Aggregated Data</th>
<th>Innovation (n=9 dyads)</th>
<th>Traditional (n=9 dyads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code 1. Case 2 is least fair</td>
<td>7</td>
<td>5 of the 14 individuals</td>
</tr>
<tr>
<td></td>
<td>7 dyads</td>
<td>3 dyads</td>
</tr>
<tr>
<td>Code 2. Notice that Case 1 and Case 3 are hard to differentiate.</td>
<td>7</td>
<td>5 of 14</td>
</tr>
<tr>
<td></td>
<td>7 dyads</td>
<td>0</td>
</tr>
<tr>
<td>Code 3. Notice that Case 3 has more rolls and make a judgment</td>
<td>6</td>
<td>5 of 12</td>
</tr>
<tr>
<td></td>
<td>6 dyads</td>
<td>2</td>
</tr>
<tr>
<td>Code 4. Find E</td>
<td>7</td>
<td>5 of 14</td>
</tr>
<tr>
<td></td>
<td>7 dyads</td>
<td>8</td>
</tr>
<tr>
<td>Code 5. (E-O) and/or (E-O)^+</td>
<td>4</td>
<td>5 of 8</td>
</tr>
<tr>
<td></td>
<td>4 dyads</td>
<td>7</td>
</tr>
<tr>
<td>Code 6. ÷N OR ÷E to differentiate cases</td>
<td>3</td>
<td>5 of 6</td>
</tr>
<tr>
<td></td>
<td>3 dyads</td>
<td>7</td>
</tr>
</tbody>
</table>

**Discussion**

In this study, there were clear differences between Innovation dyads and Traditional dyads in their approach to solving statistics problems. The Innovation condition successfully guided participants’ attention to relevant variables, and in some cases further guided them to develop near-expert mathematical solutions. In contrast, the Traditional dyads received the canonical formula and tended to focus on computational accuracy, giving less attention to understanding why or how the chi-square formula works.

These behavioral differences appeared to have important implications for learning. First, many more participants in the Innovation condition subsequently succeeded on a challenging transfer problem (taken individually). Only one of the 18 Traditional participants solved the double-transfer problem successfully versus five for Innovation. Second, the Innovation practice problems were diagnostic. Innovation dyads tended to have difficulty in developing a general formula that differentiated all three contrasting cases (dice). Those who struggled at translating their perceptions or verbal understanding into a mathematical formula struggled on the subsequent transfer problem. However, members of Innovation dyads who succeeded at differentiating all three cases on the practice problems succeeded on the transfer problem (except one). This suggests a moment where teachers could offer targeted and effective scaffolding. Such teachable moments were apparent in the transcripts of the Innovation dyads but not of the Traditional dyads because they tended to calculate the correct answers during the learning phase.

While these results support others’ findings that success during problem solving does not necessarily indicate deeper understanding, they also raise questions about what productive failure during innovation-oriented learning activities consists of (Kapur, 2010). On average, the failure of the Innovation participants to invent the chi-square formula during the learning phase did not preclude them from future success on transfer (and greater success than the Traditional condition). In this sense, the notion of productive failure during innovation activity applies to this study. However, only those Innovation participants who invented a near-expert solution during the learning phase succeeded on the target transfer posttest question. This suggests that meeting key indicators of progress during “productive failure” innovation activities may be necessary for deep understanding from subsequent lessons. The contrasting cases in the current study seemed particularly important to ensuring such progress. It was clear from the transcripts that many of the successful Innovation dyads may have settled for a more simplistic mathematical solution had the contrasting cases not blocked those
initial attempts. We suspect that inventing experiences that specifically push students to notice and relate key variables in ways that yield perceptible progress during the activity (e.g., allow students to differentiate more cases) are likely to facilitate their understanding and offer teachers more opportunities for effective scaffolding and teaching.

References


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