Is Collaborative Grouping an Effective Instructional Strategy?

Using IMMEX to Find New Answers to an Old Question

By Eddie Case, Ron Stevens, and Melanie Cooper

While problem solving is a generally accepted goal of most science courses, it has previously been difficult to determine the extent to which students' problem-solving abilities are impacted by these courses. Interactive Multi-Media Exercises (IMMEX) is a web-based software package that can deliver multiple cases of case-based problems and keep track of the information students use in solving the problems. Analysis of this tracking data provides insight into the strategies being employed by students. This study uses the IMMEX system to determine the effects of collaborative grouping on the problem-solving strategies of students in first-year chemistry courses.

We begin with problem solving because it represents the ultimate goal of chemistry education. Individuals who can address novel situations and arrive at a suitable course of action are valued in society. Such behavior is what we mean by problem solving.

—J. Dudley Herron

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The ability to solve problems is a generally accepted goal of general chemistry courses. To accomplish this goal, students may be exposed to a variety of assignments and activities that are designed and selected because they are expected to improve students' abilities to solve problems. While it is possible that these activities are designed based on problem-solving research, they may never have been evaluated as to their effectiveness in actually improving the problem-solving skills of students. One reason for this is the difficulty in assessing problem-solving skills. Basing assessment on success (getting the "right" answer) does not account for the variety of paths a student may take in solving the problem.

There has been a great deal of research into the nature of problem solving and the resulting literature examines how characteristics of the problem and the student affect students' success (Taconis, Ferguson-Hessler, and Broekkamp 2001; Kwon et al. 2000; Kwon and Lawson 2000). A variety of interventions that are intended to improve the problem-solving skills of students have been developed based on this research (Duch 1996; McIntosh 1995; Bagayoko, Kelley, and Hasan 2000). There is also a growing body of research that assesses the effectiveness of these interventions. One such intervention that has been recommended is small-group learning. Small-group learning may include specific teaching methods such as cooperative and collaborative learning. While *cooperative learning* is usually defined as small-group learning meeting a set of rather strict criteria, *collaborative learning* is a more general model where students work together to achieve a common goal. These teaching models have been well researched across grade levels and disciplines and continue to show success in improving student achievement (Bowen 2000; Qin, Johnson, and Johnson 1995; Slavin 1991; Springer, Stanne, and Donovan 1999). There are also some data that may support their use as an intervention for improving problem-solving strategies. One of the difficulties in assessing the successfulness of interventions is in determining how, and if, students' strategies have improved. Computer technology now makes it possible to track how students use information to solve problems and then to identify the strategies used. The Interactive Multi-Media Exercises (IMMEX) is a software package that shows promise in such applications.

The IMMEX package

IMMEX is used to teach problem solving using case-based problems. Initially developed as a means of presenting immunology case studies, the IMMEX package now includes problems in a variety of subject areas and at levels ranging from kindergarten through medical school. Research on the usefulness of IMMEX problems for assessing problem-solving ability and for improving problem-solving strategies has been conducted across content areas and at a variety of grade levels. This study uses the ability of the IMMEX system to present problems to students in an interactive format using real-world, case-based scenarios and to keep track of the information students use to arrive at a solution. This study further uses artificial neural networks and hidden Markov models (HMM) to extend the analysis capabilities of the package to identify specific strategies and to group these into more general problem-solving states. For the purposes of this study, each attempt by a student to solve a given case of a problem represents a *performance* and each of these performances is represented by the series of menu items the student uses to arrive at a solution. Artificial neural network (ANN) analysis clusters performances that use similar selections of menu items into a number of "strategies" (Vendlinski and Stevens 2000). Finally, because students may transition from one ANN strategy to another as they solve multiple cases of a problem, HMM is used to group similar strategies into a smaller number of problem-solving "states" (Stevens et al. 2004). These states include strategies that are similar in the information being used to solve the problem. By determining the solve rate for each state, more successful states can finally be identified.

The IMMEX system allows teachers to present multiple cases, or *clones,* of case-based, real-world problems. Each of the clones begins with the same prologue, which presents the scenario and explains the problem to be solved. This prologue gives a limited amount of background information necessary to get started on the problem. The package then presents a selection of menu items that give information that may be useful in solving the problem. Clones of a problem differ in the specific information provided by these menu items. The changes in information lead to different solutions to the problem. Students choose menu items as they navigate through the problem space, gathering information that will be useful in solving the problem. When students have sufficient information to solve their problems, they select the "Solve" item from the menu and then select their answer from

FIGURE 1

Screenshot of the prologue for Hazmat Holiday Special. The prologue identifies the problem students will attempt to solve.

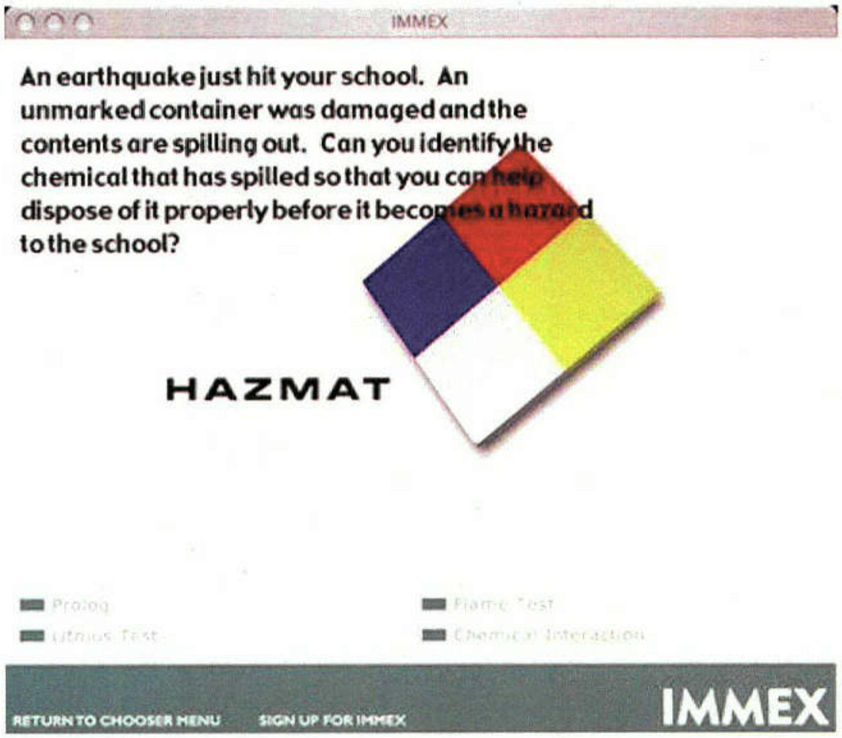


TABLE 1

Menu items available for solving Hazmat Holiday Special.

Navigation	Library	Stockroom inventory	Physical tests	Chemical tests
Prologue	Conductivity display	View inventory	Conductivity test	Blue litmus
Solutions	Chemical properties		Flame test	Red litmus
Epilogue	Flame color		Solubility in water	Barium nitrate
	Glossary			Sodium hydroxide
	Litmus reactions			Silver nitrate
	Solubility table			Sodium sulfate
	Solubility rules			Potassium iodide
	Periodic table			Hydrochloric acid

TABLE 2

Cross tabulation of state versus solve rate for the entire population solving Hazmat Holiday Special.

			Unsolved	Solved	Total
State	1	Observed	3,985	3,506	7,491
		% within STATE	53.2%	46.8%	
	2	Observed	3,155	4,022	7,177
		% within STATE	44%	56%	
	3	Observed	2,208	1,762	3,970
		% within STATE	55.6%	44.4%	
	4	Observed	314	372	686
		% within STATE	45.8%	5,4.2%	
	5	Observed	523	2039	2,562
		% within STATE	20.4%	79.6%	
	Total	Observed	10,185	11,701	21,886

a list of choices. Students immediately knows if they have solved the problem correctly and can repeat the same clone of the problem one or more times as determined by the instructor. Once all of the attempts have been exhausted without a successful outcome, an epilogue is presented that explains one possible strategy for solving the problem.

The study

A quasi-experimental, single-group study with pretest/posttest design was conducted in the fall of 2002 to determine how solving problems in collaborative groups would affect the problem-solving strategies of general chemistry students. The general chemistry sequence consists of two four-hour courses (CH 101 and CH 102). Students are required to enroll in a three-semester-hour lecture section and a one-semester-hour laboratory section. The laboratory meets weekly for a three-hour block. Rather than the traditional weekly, prescribed labs used to confirm chemical concepts presented in the lecture portion of the course, students complete three to five open-ended projects over the course of the semester. The focus is on application rather than confirmation. Students work in collaborative groups of three to four students to design and implement procedures for solving a chemistry-related problem. Students are randomly assigned to groups at the beginning of the semester with efforts made to keep groups heterogeneous with respect to race and gender.

In the fall of 2002, all of the 71 sections of CH 101 laboratory were included in the experiment with a total of 1,536 students participating. Approximately 25 teaching assistants (TAs) were responsible for these labs. During the fourth week of the semester, students were given instructions for logging on to the IMMEX system and were asked to complete a number of clones of a demo problem to familiarize themselves with the IMMEX system. During the fifth week of the semester, students were given an assignment to complete a single case of the IMMEX problem "Hazmat Holiday Special" (see Figure 1) prior to attending lab. Students then worked in collaborative groups to solve five to seven cases of the problem during the laboratory period. Students were assigned a final case of the problem to be solved individually after the laboratory period. Students were assigned a grade based on the total number of cases solved correctly (including individual and group performances) and were allowed to solve extra cases to reach the maximum score.

This study was conducted using the IMMEX problem Hazmat Holiday Special. Hazmat is a qualitative analysis problem in which students may choose to view the results of a variety of physical and chemical properties of an unknown ionic compound in order to determine its identity. The menu items available for solving the problem are identified in Table 1. Hazmat was chosen for this analysis because of its relevance to the course as well as the richness of data available. Over 7,000 cases of Hazmat have been attempted through the IMMEX system, providing a large data set for developing the HMM and providing a strong basis for comparison. Additionally, Hazmat is similar in design and solution to the first project completed in the laboratory (Cooper 2003).

The results

With 22 menu items available and with students having the opportunity to select any number of these menu items, the number of possible combinations of items a student may use in attempting to solve the problem is enormous. This makes comparing performances by hand impractical, if not impossible. ANN was used to compare performances. ANN clusters performances based on the menu items selected and each performance is then assigned to one of these 36 clusters or *strategies*. ANN assigns the performances to the strategy to which it is most similar, based on the collection of menu items the student selected in attempting to solve the problem.

As a student solves multiple cases of a problem, the sequence of strategies on subsequent problems can be used to identify distinct states using HMM. These HMM states then represent clusters of similar ANN strategies. In this study, HMM is used to assign each performance to one of five states. Examination of the five states can indicate which states are most successful at providing a correct solution to the problem. Table 2 is a crosstab analysis of state versus solve rate for all performances of Hazmat through the time of this study. These data show that of the five states, state 5 is the most successful with states 2 and 4 also showing solve rates of greater than 50%. Based on this data, it would be most advantageous if performances were in states 2, 4, or 5. More information is needed about the particular states before conclusions can be drawn about which states represent the most desirable problem-solving strategies.

A closer examination of the states and the strategies they represent shows striking similarities between the strategies within each state. The strategies in states 1 and 3, for example, include most of the performances in which a majority of the 22 menu items are chosen well over 50% of the time. These more prolific strategies correspond to the least successful states as shown in Table 2. States 2 and 4, on the other hand, include mostly strategies in which students use a more reasonable number of menu items. These more efficient strategies are among the more successful states in Table 2. Finally, the strategies included in state 5 represent performances in which fewer than 5 of the 22 menu items are used in more than 20 to 30% of the performances included. Even though these correspond to more successful states, it would seem that other factors such as guessing

FIGURE 2

Distribution of all attempts at solving Hazmat Holiday Special across states for the overall population and groups of study participants.

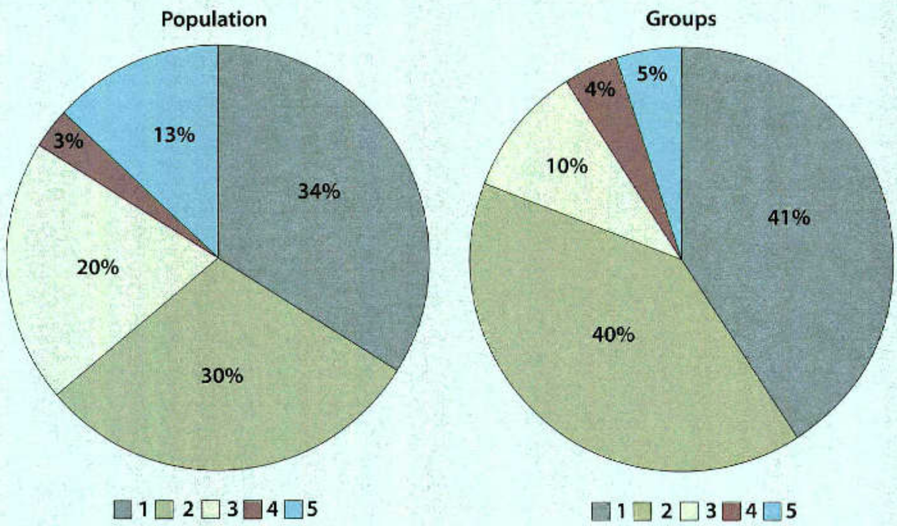


FIGURE 3

Distribution of participants' individual attempts at solving Hazmat Holiday Special before and after grouping.

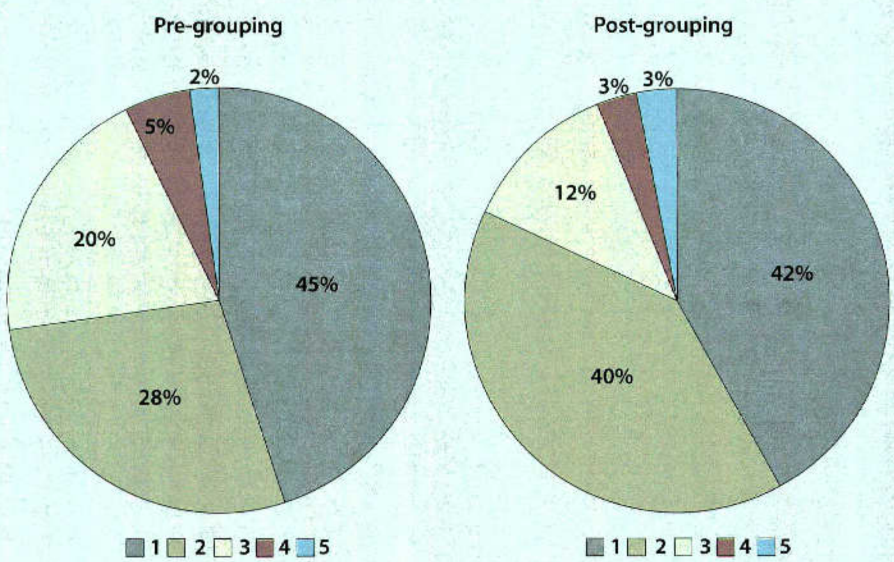
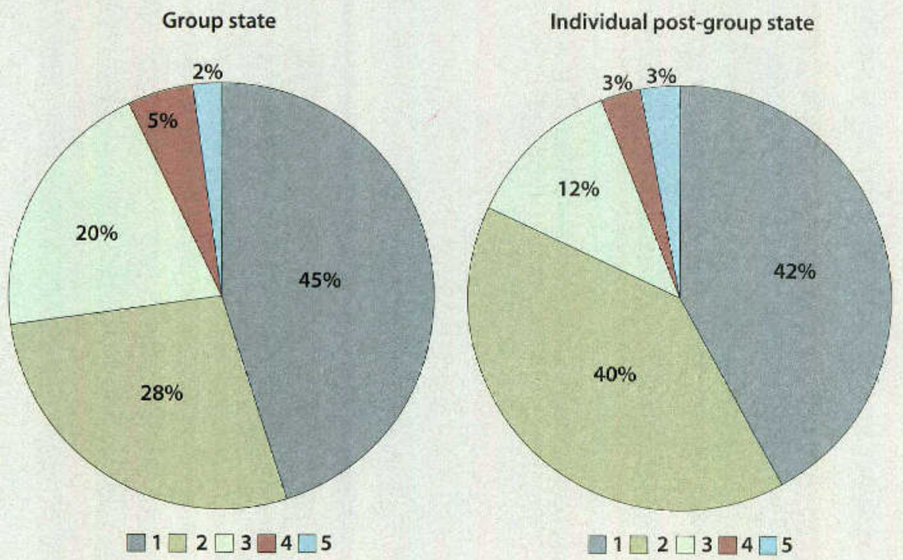


FIGURE 4

Distribution of performances across states for all group attempts and for participants' first individual attempt after grouping for solving Hazmat Holiday Special.



or gaming strategies contribute to the successful solve rates. This type of analysis leads to the conclusion that states 2 and 4 represent the most desirable approaches to solving this particular problem.

To compare the problem-solving states used by groups to those used by individuals, the performances for the participants working in collaborative groups were compared to all the performances of the overall population solving Hazmat. Figure 2 shows the distribution of performances across states for the population and for groups involved in this study, X^2 (4, $N = 21886$) = 386.36, $p < 0.001$. It is evident from this illustration that the largest difference between the two is in the increase in the number of performances in state 2 and in the decrease in the number of performances in states 3 and 5. Statistically, the proportion of group performances identified as efficient (states 2 and 4) is greater than the number of performances within the overall population in these states ($z = -13.17$, $p < 0.001$). Because state 2 represents more efficient strategies, it would appear from the data that grouping has led to the use of more acceptable strategies in solving problems.

To determine if working in groups caused students to change their strategies, a comparison was made between the distribution across states for the initial performances of the individuals participating in the study and their individual performances immediately after grouping. Figure 3 shows that the greatest differences in the distributions are in the number of performances in states 2 and 3, X^2 (4, $N = 1536$) = 38.62, $p<0.001$. There is a statistically significant increase in the number of performances in state 2 ($z = 5.08$, $p < 0.001$) from 28% to 40% and a corresponding decrease in the number of performances in state 3 ($z = 3.94$, $p < 0.001$). This would indicate that collaborative grouping caused students to abandon less successful, prolific strategies in favor of more successful, efficient ones. Based on these data, it can be predicted that between 7.4% and 17% of students will transition to state 2 as a result of solving problems in collaborative groups at the 95% confidence level.

A correlation between the performances of the collaborative groups and the performances of the individuals immediately after grouping would indicate that the strategies employed by the groups may have affected the strategies individuals used after the collaborative grouping. Figure 4 shows the distribution of the final performance by the collaborative groups across the HMM states and the distribution of the initial performance by the individuals after working in the collaborative groups. There is no significant difference between these distributions, X^2 (4, $N = 3627$) = 8.905, $p > 0.05$. This indicates that working in collaborative groups was effective not only in changing the strategies used by the individuals. It shows that strategies employed by the groups in solving problems may determine the strategies the individuals will continue to use after grouping. Specifically, there are data to support that students working in collaborative groups employ more effective problem-solving strategies than do individuals, that students who work in collaborative groups use more effective strategies when they work independently after working in groups than they use prior to grouping, and that students continue to use the strategies employed by the collaborative groups when they work independently after working in groups.

Conclusions

One of the potential drawbacks of collaborative grouping is that gains made by groups may not carry over to individual performances. This study shows that solving problems in collaborative groups positively affects the problem-solving strategies used by the individuals after the grouping situation has ended. In addition to the changes in problem-solving states represented by the pretreatment/posttreatment comparison presented above, the data also show that the treatment improves the solve rate for the individuals involved. The solve rate for the individuals improved from 52.8% pretreatment, to 63.5% posttreatment. This compares to a rate of 55% for the overall population after seven performances. Finally, the similarities between the distribution across states for the groups and the posttreatment individuals support the conclusion that the gains made by the groups do, in fact, carry over to individual performances. The data show that collaborative grouping does positively affect the problem-solving strategies of the individuals in the groups.

Implications for teaching

One of the concerns that has been raised with respect to teaching problem solving is the lack of data to show that interventions can be used to improve the problem-solving strategies of students. A strong contributing factor to that lack of data was the difficulty in assessing problem solving. By using the ability of the IMMEX software to go beyond measuring student success in solving problems, this study has shown that it is possible for a teaching strategy to improve the problem-solving strategies of general chemistry students. Although the study specifically addresses the success of collaborative learning as an intervention, there is the possibility that other strategies may produce similar results. At the very least, chemistry instructors may use this research as the basis for using and developing interventions that may improve student problem solving. Specifically, this research supports the usefulness of informal, collaborative grouping as one such strategy. Much of the research on using groups as an instructional strategy focused heavily on well-structured, formal groups such as those described by Bowen (2000); Qin, Johnson, and Johnson (1995); Johnson, Johnson, and Smith (1991); and Slavin (1991). Such grouping strategies may be well suited for high school chemistry classes or small-enrollment university courses, but the structure required becomes difficult as enrollment increases. The general chemistry classes at the participating institution may range in size from 100 to over 200 students in a single section. Further, the course is taught in a lecture hall with auditorium-style seats affixed to the floor, which limits the extent to which formal groups can be formed in the classroom. The challenge, then, is to find ways to take advantage of the gains demonstrated by the cooperative-learning research, in a setting where such structure and formalization are not possible. This study shows that even informal collaborative groups working together to solve a common problem can improve the problem-solving strategies used by students involved. Accordingly, general chemistry instructors should feel justified in incorporating collaborative learning activities into their repertoire of methods for teaching problem solving to their students. ■

Acknowledgment

This work was supported in part by the National Science Foundation under grant CCLI 01206050.

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