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Successful Curriculum Development and Evaluation of Group Work in an Introductory Mineralogy Laboratory

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ABSTRACT

Mineralogy is a core topic for tertiary geoscience programs worldwide. We report on the use of laboratory group work as an effective and integral part of a new introductory mineralogy curriculum at the University of British Columbia. The new laboratory curriculum was developed by incorporating student feedback with evidence-based pedagogies. These pedagogies include (1) learning goal–based restructuring of content, (2) use of applied topics (e.g., economic mineralogy) and custom projects to promote student engagement, and (3) use of group work and group assessment in order to provide students with opportunities for peer-supported learning and meaningful feedback from teaching assistants (TAs). The new curriculum was evaluated by using a pre- and posttest system and anonymous student surveys in the 2008 and 2009 fall terms. The pre- and posttest results indicate that groups performed better than did individual students, with groups of three and four showing the most positive effects, albeit in different ways. In addition, successful collaboration within groups led to an overall improvement in student performance over the term, with most groups showing an overall larger "success" in the posttest than in the pretest, and the range in student scores within groups getting smaller (by members benefiting from group peer education). Student surveys showed student satisfaction with the new laboratory curriculum and the use of group work and group assessment. Future improvements include the use of a validated instrument in order better understand learning gains and better use or training of TAs to encourage and maintain positive group dynamics. © *2012 National Association of Geoscience Teachers*. [DOI: 10.5408/10-212.1]

Key words: mineralogy, lab, group work, collaboration, curriculum development, group size

INTRODUCTION

Introductory Mineralogy is typically a foundational course in a geosciences degree program and is a prerequisite for other core topics (e.g., petrology, field geology). All Earth scientists learn about minerals and their properties, as they are the fundamental building blocks of the Earth (Hawthorne, 1993). There is ongoing discussion in the geological community on the curriculum and the way in which this subject is taught (Constantopoulos, 1994; Brady et al., 1997; Dutrow, 2004; Reinhardt, 2004; Swope and Giere, 2004; Perkins, 2005; Boyle, 2007; Mogk, 2007; Wirth, 2007). This discussion is represented by a continuum of mineralogy courses that exist between "traditional" crystallographic theory–based and practical identification–based mineralogy needed for petrology subjects (Dutrow, 2004).

Mineralogy courses often have a laboratory module, which is used to teach both the theory and the practical skills needed for mineral identification. The American National Research Council defines laboratories as "[places] where students interact directly with the material (or with data), using tools, data collection techniques, models and theories of science" (Singer et al., 2005). Faculty and alumni of the geosciences consider laboratories (or an equivalent format) essential for teaching the necessary basics of mineralogy and petrology (Plymate et al., 2005). The 2.5-h, weekly laboratory sessions discussed in this paper are a part of a new mineralogy curriculum at the University of British Columbia (UBC), which have been designed to integrate both theory and mineral identification. Laboratories offer an excellent stage for learner-centered environments that require active and collaborative learning. In this paper, we discuss the use of group work as an effective part of the laboratory format in the Introductory Mineralogy course at UBC. The Introductory Mineralogy laboratories are introduced below.

MINERALOGY AT UBC

At UBC, mineralogy focuses primarily on crystallography and hand-sample identification techniques. The mineralogy course size typically ranges from 100 to 110 students per semester, with five different laboratory sessions of 12–30 students each, each taught by one graduate teaching assistant (TA).

Like other institutions with large class sizes and limited budgets, UBC had low TA-to-student ratios and therefore provided only limited opportunities for personal and meaningful student–laboratory instructor interactions (Goodman et al., 2005). Students worked individually through the weekly laboratory activities from a crystallography text by Klein (2007), and many students would leave before they had finished, as the laboratory work was not assessed on a week-to-week basis.

In early 2008, student feedback was collected regarding the positive and negative aspects of the Introductory Mineralogy course. Figure 1 illustrates the range of likes and dislikes from their responses, relevant to the laboratories. The most common like was the mineral identification aspect. The most common dislikes were that the laboratory sessions were too long, the laboratory text was bad, and

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A. Question 1: What aspects of the lab did you most like?	n=18
Mineral identification was useful	9
Hands-on aspects of lab	1
Teaching assistant's were really helpful	4
Better than lecture for learning about minerals	4

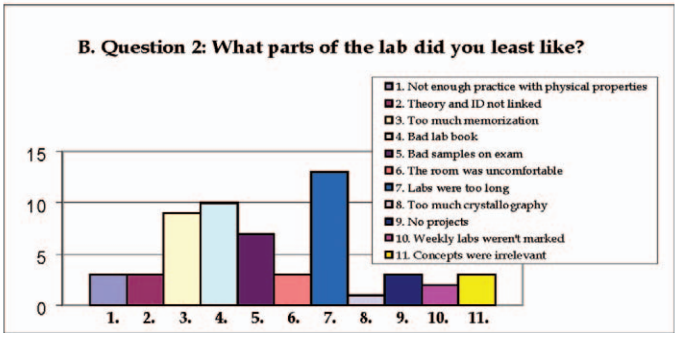


FIGURE 1: Student feedback ($n = 44$) collected in 2007 and 2008 from informal student surveys and a small focus group. This feedback reflects the 2007 laboratory curriculum. Students were asked two open-ended questions, (A) the likes and (B) dislikes.

there was too much memorization of content. The primary pitfalls of the laboratory sessions included lack of organization, running overtime, a laboratory text that did not match the context of the course, and too much memorization.

Because of negative student feedback, the Introductory Mineralogy course was restructured as part of the Carl Wieman Science Education Initiative (CWSEI; Carl Wieman Science Education Initiative, 2009). The primary objective was to align the laboratory component with pedagogy, encouraging student engagement. Redesigned objectives for the laboratories were set to address the main issues identified through the student feedback along with learning techniques grounded in the science education literature (see "Methods: Restructuring UBC's Introductory Mineralogy Laboratory" for more details). The objectives included:

1. Learning goal–based restructuring and reduction of the volume of the laboratory content to encourage scaffolding of topics and to reduce the cognitive load (the burden placed on student's working memory during instruction (Chandler and Sweller, 1991) of the weekly laboratories sessions.
2. Use of laboratory activities with applied topics (e.g., economic mineralogy, career applications, or advanced petrology topics) and customized individual projects. These encourage students to see the economic–academic importance and personal relevance of mineralogy.
3. Evaluation and assessments that provide weekly, meaningful feedback.
4. Use of group work to utilize peer-supported learning, encourage engagement, and satisfy logistical purposes such as TA weekly budgets.

In the next section, we discuss the rationale for these changes and the implementation of the curriculum and group work in more detail.

METHODS: RESTRUCTURING UBC's INTRODUCTORY MINERALOGY LAB

Changes made to UBC's Introductory Mineralogy laboratories took place over 2 y and in two stages. Stage 1 took place from January to August 2008. It focused on the development of learning goals, pedagogy, and assessments. Stage 2 took place just prior to the 2009 fall semester and consisted of fine-tuning the changes from stage 1, based on student feedback from 2008. Data were collected during the fall semesters of 2008 and 2009. An overview of the data collection can be found in Table I.

Stage 1: Original Redesign 2008

Learning Goal–Based Restructuring and Reduction of the Cognitive Load

Learning is aided by proper organization through clearly communicated objectives by using learning goals (Lord and Baviskar, 2007; Krajcik et al., 2008; Simon and Taylor, 2009). Learning goals are especially important in courses with laboratory components. Course-level learning goals were developed (Table IIA) and placed into a linear structure where teaching of the nonsilicate minerals occurred first, followed by silicate minerals. Topic-level goals were often grouped into specific, repeatable, categories (see Table IIB), allowing us to easily link the laboratory assignments with the topics discussed in the lecture. Integrating laboratory experiences with lecture experiences helps students develop a mastery of the knowledge (Singer et al., 2005) through repetition and inquiry.

Learning goals also help students and instructors identify what the important topics are. This gives us the ability to eliminate the extraneous activities that could be perceived as "busy work" by students, thus reducing the cognitive load. The attitude of "less is more" can be useful in curriculum design and help instructors reduce the amount of content while introducing the relevant concepts in a meaningful way (Dempster, 1993). One of the major criticisms of the previous design was that the laboratory sessions were too long, and the material required too much memorization (Fig. 1B). Reducing the amount of material that students are responsible for is a first step in reducing cognitive load. In consultation with faculty teaching in the upper-division courses, the number of required minerals that students were responsible for identifying was reduced from 75 to the most common 55 minerals.

As our focus had changed, we wrote a new laboratory manual text that reflected the learning goals. These new laboratory sessions are shorter than those found in traditional crystallography texts, and are designed to fit the 2.5-h time slot. The activities are focused on inquiry-style activities, in which mineral identification techniques and observation skills are used to measure physical properties. By moving away from repetitive, "recipe-like" procedures, we hoped to encourage understanding rather than memorization. In the previous laboratory format, students were asked to complete 30–40 problem sets of crystallography theory, and then proceed to catalog the diagnostic properties of 10–15 minerals. In the new format, students work through four laboratory activities that include three to five questions each, and use the minerals to help answer these questions. These new activities were designed to inspire deeper learning through a tactile approach to the scientific method. We aimed to reach a higher level of engagement by using

TABLE I: Description of data collection.

Date	Description
Fall, 2007	Informal feedback survey of one lab section (Dohaney) ($n = 18$)
January–August 2008	Student attitude and feedback collected via emails (Kennedy) ($n = 21$)
Stage 1 Fall, 2008	Small focus group in order to assess lab design (Labs 1& 2) ($n = 5$) Pre-test (individual and group) ($n = 99$) Midterm feedback survey ($n = 33$) End of term feedback survey ($n = 56$) Post-test (group) ($n = 108$) All lab grades (i.e. mineral tests, and final lab exam scores; $n = 112$)
Stage 2 Fall, 2009	Pre-test (individual and group) ($n = 100$) Midterm feedback survey ($n = 49$) Post-test (individual and group) ($n = 99$) All lab grades ($n = 103$)

comparative and observation skill-based learning goals such as *application* (e.g., use, demonstrate, examine, illustrate), *analysis* (e.g., distinguish, compare, differentiate), and *evaluation* (e.g., evaluate, compare; Isaacs, 1996; Lord and Baviskar, 2007). An example of one of these laboratory activities is to use the streaks of 10–15 sulfide and oxide minerals to differentiate them from one another. Outside of laboratory time, students are required to look up mineral properties (e.g., mineral streaks) in a reference text or mineralogical Web sites to confirm their observations. Although the laboratory activities are to be completed individually, students are encouraged from the very beginning of the semester to work collaboratively and discuss the laboratory activities as a *group*.

Focus Group

We field-tested the new laboratory goals and organization with a small focus group ($n = 5$) of students who had taken the course in the previous year. The focus group took place in mid-2008, when the laboratory manual was under construction, prior to the 2008 fall semester. The purpose was to obtain student feedback and assess their performance (pre- and posttests) on two new laboratories (1 and 2). The durations of the laboratory sessions were timed and shown to be between 50 and 90 min, well within the scheduled laboratory time. Students were broken into two groups and were tested as a group, before and after working through the laboratory material. They performed very well on the pretest (average individual score of 74.1%), which is expected, as they would have been introduced to some of the content in the semester before. Posttest group scores were higher than individual scores by 15%–20% (group 1, laboratory 1: 85%; and group 2, laboratory 2: 97%). However, responses and performance are not representative of students who would be encountering the mineralogy content for the first time.

The students indicated that the new goals provided motivation and were useful and clear. In addition, the students thought that collaborative (in this case, paired) learning was useful and helpful for learning. One student stated, "I like [group learning]; it's like we solved it from different perspectives."

Use of Applied Topics and Customized Student Projects

It is difficult for students to be motivated to do exercises if there is not any context for *why* they are learning (e.g., Bransford et al, 2000). Student feedback from 2007 also reflected the need for context, as indicated by a representative student comment "I really think the focus of the

TABLE II: Introductory mineralogy course-level goals and categories.

A. Learning Goals. *By the end of this course, students should be able to…*
1. Use atomic structure and crystallography to identify and explain the properties and groupings of common minerals.
2. Explain correlations between relevant chemical concepts (e.g. substitution and solid solution) and the parts of the mineral formulas that control the properties and groupings of minerals.
3. Describe and explain the processes and environments that lead to common associations of minerals in rocks.
4. Observe, describe, and measure physical properties of mineral hand specimens in order to identify minerals and place them into groups.
5. Develop interpersonal and practical skills, which are useful for future careers such as working in groups to make decisions, and preparing individual laboratory term projects.
6. Apply mineralogy concepts and skills learned in lecture and lab to geological, materials science, environmental, and economic topics.
7. Appreciate the rarity, beauty, and usefulness of Earth's minerals.
B. Topic-level goal categories. *These were used to link the topics in lectures to the lab activities. Each week, these topics were covered:*
1. Basics of Mineral Chemistry and Physics
2. Mineral Identification Techniques, and the Science behind them
3. Applied topics: Guest lectures, Upper-year topics, Economic Mineralogy etc.

laboratories should be in the minerals, as we are more likely to use this info in the field.'' Real-world applications can be the most direct method of demonstrating the context and purpose of conceptual learning. We tried to accomplish this by using applied topics, and two individual, customized student projects. In the new laboratory manual, each laboratory has at least one activity that requires students to apply basic concepts to a problem or applied topics (e.g., diamond exploration). The most relevant applied topics incorporated petrology concepts, such as mineral assemblage associations, crystal formation and growth conditions, and rock specimen modal mineralogy. These topics allow an introduction to the basic hand-sample petrology skills needed for later courses in their degree program.

We also created two individual assignments, the MinBook and the Poster Session. These projects served a motivational purpose by allowing students to explore their individual creativity and to develop autonomy and resourcefulness. Individual projects require students to organize the material in a way that makes sense to them, helping to create meaningful cognitive frameworks for the information and allows them to retrieve it more effectively (Edelson, 2001).

The MinBook assignment required students to look up, test, verify, and catalogue the properties and characteristics for each of the 55 required minerals. The project was used as a study aid, and ideally, students should have contributed to it weekly as they encountered new minerals. The objective of this was to produce personalized reference documents that students could use in subsequent years of study. This encouraged students to focus on observing mineral properties and to catalogue these in their MinBook rather than only memorizing mineral characteristics. A major part of their MinBook was for students to create a reference system that allowed them to use the properties of the minerals to eliminate each grouping of minerals systematically during identification, and to organize their book in a personally meaningful ways.

The Poster Session was a short oral presentation of a poster that each student created about a mineral of his or her choice. The minerals selected were not on the required mineral list. In both projects, students were asked to use external laboratory resources such as Web sites, textbooks, and journals. Research shows that students will learn more effectively when concepts are reinforced outside of the laboratory or lecture environment (Singer et al., 2005). Students and TAs were given rubrics so that expectations and marking were clear.

Evaluation and Assessments

Assessment is an integral part of feedback and can be a source of motivation for students. Most students value many opportunities to articulate their ideas on their own, and value any personal feedback they receive (Singer et al., 2005). Prior to curriculum development, the Introductory Mineralogy course at UBC had several assessments that were performed in the laboratory, including mineral identification tests and a laboratory examination. The worth of the laboratory portion of the course did not change from previous years, and remains at 40% total (which includes mineral tests, student projects, and a final laboratory examination).

In mineral tests (two tests per term, each worth 5% of the total laboratory grade), students were given 25–30 minerals (one at a time) and had to use their mineral identification techniques to identify which mineral was presented to them. Students were marked on correct identification (1 mark) and the correctly spelled mineral formula (1 mark). This scheme encouraged rote memorization.

The revised test emphasized observations and correct use of mineral identification skills. The marking scheme was changed to award 1 mark for correct identification, and 2 marks for two diagnostic properties that led to this identification. While the test remained closed book, the shift in marking was to discourage students from relying on memorization, and to encourage identification techniques and recognizing diagnostic properties of minerals. Laboratory activities in the new laboratory manual were also primarily focused on the chemistry of minerals (for example, cation substitution or chemical-based mineral groupings), replacing the need for memorization of mineral formulae.

The previous Mineralogy laboratory included a laboratory examination for which the content was centered on crystallography. No hand samples were used in this format. In an effort to move away from a crystallography theory–based format and align with the new learning goals, the new laboratory examination (worth 15% of the total) was predominantly practical skill-based. We gave students several hand samples with minerals that display characteristic properties (such as crystal habit and form) and rock specimens in order for students to deduce mineral associations and environments.

In the previous format, students were not graded weekly, and this led to a lack of motivation for students to attend laboratory sessions and to complete them. We designed ''group quizzes'' (seven quizzes worth 1% each) to be completed at the end of each laboratory. Group learning had not been emphasized and rarely used in the previous format of the class. A description of why we chose to use group work and group assessment is in the following section.

Justification and Use of Group Work and Group Assessment

Unstructured group work and group assessment was introduced in the laboratory sessions primarily for logistical reasons. Teaching in the laboratories in North America is often done by graduate student teaching assistants (TAs), depending on the size of the department, student population, and resources available. In order to accommodate large laboratory sizes and insufficient TA marking hours, we encouraged group work during laboratory time, followed by a short, structured, group quiz. The quizzes would be marked weekly, and provide meaningful feedback to be given to students the following week. With a class population of approximately 100 students, group quiz marking (rather than using individual quizzes) could reduce the weekly marking budget by up to 50%–75%. In addition, in-laboratory group work allows for more constructive and focused use of the TA's time in laboratory in order to provide more meaningful feedback to students.

Fortunately, the logistical reasons for group work have a useful pedagogical by-product. Group work was used here primarily to encourage peer discussion during the weekly

TABLE III: Pre- and posttest questions and answers 2009[1].

Question(s)[2]	Learning goal	Topic-level goal category(ies)
1: *What do you think a diagnostic property for identifying minerals is? Explain in as much detail as you can, giving a relevant example. (2 marks)* Ideal student response: "It's a physical property that's unique to the mineral and helps us identify it in hand sample. Example: cleavage; in amphiboles you can sometimes see characteristic 60–120 degree cleavage, in two directions."	4, 6	2
2: *Diamond and graphite have very different properties. I) What is the main reason for their differences? (1 mark); II) What environment do you think diamond forms in? What about graphite? (2 marks)* Ideal student response: *I.* "The main reason is their crystal structures are different due to the different environment each forms in" *II.* "Diamond forms in a high pressure, high temperature environment, probably much deeper in the Earth. Graphite forms in shallow crustal conditions, with lesser temperature and lesser pressure."	1, 2, 3	1
3: *What are some minerals harder than others? (1 mark)* Ideal student response: "Some minerals are harder than others because they are held together by stronger atomic bonds (e.g. covalent versus van der Waals bonding) within their crystal structure."	1, 2, 3, 6	1, 2
4: *Name two physical properties that differ between the Carbonates and the Sulphides. Explain (2 marks)* Ideal student response: " 1. Specific gravity: Sulphides tend to be heavier than Carbonates; 2. Streak: Sulphides tend to have dark-coloured streaks, while Carbonates have white or colourless streaks."	1, 2, 3, 4	1
5: *Wollastonite's mineral formula is: $CaSiO_3$. Aragonite is $CaCO_3$. What is the Anion, and what is the Cation for each? (2 marks)* Ideal student response: "Wollastonite: Cation = Ca^+, Anion = SiO_{3-}; Aragonite: Cation = Ca^+, Anion = $CaCO_{3-}$."	1, 2, 4	1
6: *Why are phyllosilicates typically very soft minerals? (1 mark)* Ideal student response: "They have weak bonds between strongly bonded sheets of silica tetrahedra with OH^- and H_2O molecules in-between the sheets as well."	1, 2	1, 2
7*: *What is the unit cell of a mineral? Explain (2 marks)* Ideal student response: "It is the building block of a mineral. It's the smallest, simplest, unique, representative structure of the mineral which is repeated (in 3D) to form a mineral."	1, 2	1
* In 2008, the order of questions was different, and Question 7 was replaced with another question: *Question 7: You've collected several samples of an unknown mineral. You have used your identification techniques but still can't identify it. Describe the process that you would go through to identify the mineral. (2 Marks)* Ideal student response: "I would use an analytical technique such as X-ray Diffraction. You can crush the sample, and use the machine to match your sample to known mineral compositions and structures."	5, 6	1, 2, 3

[1]Questions are shown in italics, and answers are selected student responses that received full marks. Learning and topic-level goals are the same as those in Table II.
[2]Instructions to students: "Answer the following questions the best that you can (individually, and in groups). Draw on your science background to help. If you don't know the answer, write that you don't know. This is not graded, but used for research in your learning. GOAL: To assess your previous knowledge of mineralogy."

quizzes and laboratory work and to increase student engagement. Many studies suggest that there are advantages to group learning, specifically fostering collaborative discussion (Pray Muir and Tracy, 1999; Barron, 2010) and peer learning (e.g., Smith et al., 2009). Group (or collaborative) testing also has many advantages such as promoting critical thinking of complex situations and teamwork (Lusk and Conklin, 2003; Russo and Warren, 2009; Wiggs, 2011). This new design created a weekly opportunity for feedback from the TAs, within the format of large laboratory courses. This allowed students to make mistakes and discuss their mistakes with minimal marking penalties, while also allowing the TA sufficient time to pay attention to the learning needs of the entire class.

Group work and group testing can be useful for all students (Eaton, 2009), but specifically low achievers who are not as prepared for higher-level thinking and reasoning (Giuliodori et al., 2008; Macpherson et al., 2011). Mineralogy lies at the beginning of most degree programmes in which staff members have to teach students at widely differing stages of intellectual "readiness." Socially, students can relate to one another, fostering good interpersonal interactions (Kapitanoff, 2009), positive group experiences can lead to increased motivation to learn (Cortright et al., 2003; Slusser and Erickson, 2006) and to attend class (Michaelsen et al., 1982). One of the course-level goals is focused on development of communication and other interpersonal skills (Table II, goal no. 5), so the use of group work can be instrumental in developing these. There can also be negative impacts of group work: the typical psychological factors when peers interact include overly extroverted "take-over" personalities (Barron, 2010), and "free-ride," i.e., social loafing (Karau et al., 1993), shy, or disenfranchised students who blend into the background because it is easier (and less risky) to receive the marking benefits without participating. Participation of students can be increased if the task is considered important (increased high-marking value, such as examinations [Cortright et al., 2003]), communication is valued and productive among members, and if each member's input is respected by all members (Karau et al., 1993). However, because task value is individually defined (Ryan and Deci, 2000; Eccles, 2005), some students might feel that group marking is an unfair method of assessment and this needs to be considered.

Stage 2: Fall Term of 2009

Because of student surveys and discussions with the TAs, several small changes were made to the 2009 curriculum, based on feedback from 2008. Results are discussed in the "Results" section.

Instruments

In order to assess the impacts of the curriculum on student learning, we created a short-answer, criterion-based test that students completed (individually and then together as a group) at the beginning and end of the semester (Pre- and posttests; refer to Table I for the sequence of test taking). Questions were taken from the weekly group quizzes, each one matching one of the learning goals and content covered in each laboratory. Our objective was to select open-ended questions that could elicit a range of misconceptions. The pre- and posttest results are shown in Table III. The instrument represents the first stage of development toward a validated mineralogy concept inventory in development at UBC. We also performed standard, anonymous, voluntary, mid- and end-of-term surveys to assess students' attitudes.

Student feedback surveys were anonymous and collected through e-learning tools (Vista or WebCT). Many questions utilized the Likert scale. Questions and results are shown below.

RESULTS

Results from this study show that: (1) learning gains (determined from pre- and posttests results) in both semesters were systematically greater for the groups than for the individuals; (2) group sizes of four was more successful in this curriculum, and (3) student feedback from both semesters was significantly improved and elicited small changes to the laboratory format and assessments in the 2009, and in the future curricula.

Individual and Group Learning Gains

Results from the pre- and posttests in 2008 and 2009 indicate that students gain some conceptual knowledge throughout the semester. Figure 2 illustrates a plot of the calculated learning gain (Hake, 1998) versus the pretest scores. This plot also shows that our pre- and posttest instrument was possibly too simple (individual students and groups scored 70%–80% on the pretest, with learning gains of 0.8–1). In addition, some groups scored 100% on the posttest, achieving an unwanted "ceiling effect," which does not allow a true learning gain to be calculated for these students. The ceiling effect resulted in a non-Gaussian distribution of scores, which limited our ability to perform statistical tests on the pre- and posttest data.

Most importantly, the clustering and the average normalized learning gains from each series of data indicate that groups systematically performed better than individual students did. To better understand this observation, we looked at individual student success compared with the group in the pre- and posttests scores. Two factors were explored that could influence group success: group make-up (i.e., a grouping of similar or mixed-talent achievers) (Appendix 1), and group size (Figs. 3 and 4).

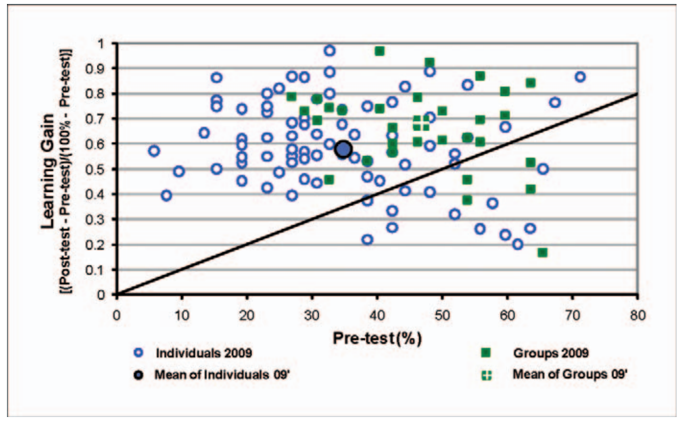


FIGURE 2: Results of pre- and posttests from 2009. This graph illustrates the calculated individual student and group normalized learning gains (Hake, 1998). The mean of the learning gains are plotted, and a line represents no change in scores (from the pretest to the posttest). Overall, the groups scored systematically higher than the individuals did. These data also illustrate that the instrument was relatively simple, because some students achieved higher pretest scores than expected.

Students were assigned into low-, medium- and, high-achiever talent categories, based on their final course grades in 2008 and 2009. Criteria for assigning students to specific categories can be found in Appendix 1. Plots ("Appendix 1," Fig. A, part B) and statistics ("Appendix 1," Fig. A, part C) of group scores, the range and mean of individual student scores, did not illustrate a correlation to group success when sorted into mixed-talent (e.g., L, M, H students) or same-talent (e.g., M, M, M students) groups.

Figure 3A compares plots of individual group member grades with the group scores of the pretests in 2008 and 2009, sorted by group sizes of two to six students. We utilized a metric to define the "success" of collaboration within a group when the group score exceeds the top student's score (Michaelsen et al. 2004). Figure 3B is a table of statistical values calculated from comparing the pretests of individuals within the group, including group success. Figure 3C and 3D illustrate similar findings for posttest scores from 2009. Individual posttest data was not collected in the 2008 semester, and was therefore omitted. Groups with two, three, and four members had group scores that exceeded top-student scores, and were therefore defined as "successful" collaborative groups. Although, for groups of two this could be an artifact because of the small number of pairs ($n = 3$). Generally, our data indicate that groups with four students might work more collaboratively (group sizes of five and six were shown to be less successful than group sizes of two to four students).

Figure 4A illustrates the differential change in group scores minus the top student score in pre- and posttests for each group in 2009. A mean positive differential for all groups indicates that group work yielded a higher group score than the top-scoring student (Fig. 4B). A comparison of the means of the differences between pre- and posttest "success" could indicate a change in collaboration within groups *during* the semester (Fig. 4B). A positive change (or a more positive differential) in the posttest versus the pretest (see the direction of the arrows in Fig. 4A) is interpreted by the group exceeding the top student scores by more. This means that collaboration has paid off, and the group effort has led to positive changes throughout the semester. However, some groups of three and four illustrate very negative changes.

In general, the posttest differentials for most group sizes are larger than the pretest values, suggesting that collaboration could be becoming better over the term and resulting in group achievement. Groups with four members displayed the largest positive differential, a larger range in differentials, and dominantly positive changes throughout the semester. Within the group size, the larger range is an artifact of the number of members per group (i.e., a group of four has more members than group of three, which results in a larger positive and negative differential values). While a group size of three illustrated less overall positive differentials (compared with a group size of four), and showed significant, incremental positive changes (Fig. 4B; group 3 had eight groups with positive changes and two with negative changes during the term).

Positive Student Feedback

Data from anonymous student feedback surveys (multiple- choice and open-ended questions) were collected in order to assess students' attitudes to the curriculum and specifically the use of group work. Average responses were calculated by taking the average and standard deviation of individual responses on the Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). Figure 5A shows the results from an end-of-term survey in 2008. Students were positive about the laboratory format and style (Fig. 5Aii), MinBook (Fig. 5Ai, question 4), and individual assessments (Fig. 5Ai, question 6; 5Aii). A large proportion of students felt that the Poster Session used in 2008 was not useful for their learning (Fig. 5Ai, question 5), and was subsequently removed from the 2009 curriculum. One student commented, "I felt it was a waste of time; it was very tedious and time-consuming." The MinBook project was also altered because of feedback. Most students felt it to be a very worthwhile exercise (Fig. 5Ai, question 4), but that it took many extra hours outside class: "It required a lot of work, and I spent more time making it than I did studying it." Therefore, the minerals included in the project were reduced from 55 to the most common 20 rock-forming minerals.

In both years, the majority of students valued the use of group work (Fig. 5Ai, questions 1 and 2; 5Aii). One student stated, "I enjoyed the group work in the laboratory. I found discussing–working through the answers to the laboratories and quizzes very helpful in understanding the course material." The graph of survey responses in Fig. 5Aii shows that the two elements of the course that the students most wanted to keep were group format and the laboratory format and style.

Based on observations from TAs in both terms, some additional changes were made. In 2009, we awarded students 3% credit at the end of the term if they had completed all the questions in the laboratory manual. TAs also expressed support for the group format. They indicated that the use of their time in the laboratory was more efficient and that marking hours were within predetermined limits.

In 2009, we decided to recommend group sizes no greater than four because of some negative group dynamics informally observed in larger groups of five and six. Negative group dynamics included segregation of members and disengagement of some students. These observations were later supported by the low differential (group-top student) values or negative changes shown by some groups (Figs. 3B, 3D, and 4A).

After minimal changes to the laboratory curriculum as discussed above, student feedback collected from a midterm survey from 2009 was also very positive (Fig. 5Bi and 5Bii). Students found some aspects of the laboratory challenging, such as the mineral identification and memorizing mineral properties (Fig. 5Bii), but continued to find the laboratory session length (and the format) useful in their learning (Fig. 5Bi, question 1). Group quizzes were also reported to have helped with their learning (Fig. 5Bi, question 2), but informal feedback from one of the TAs indicated that some groups were malfunctioning: "Some groups were not very collaborative in their group quizzes. In these groups, there were often one or two students who answered all the questions and didn't consult or even allow contributions from other group members. This was particularly obvious if certain group members were more interested in finishing the laboratory early whereas others actually wanted to learn the content." Although the weekly group quizzes were each worth 1% (of each student's total grade), some students resented the use of this format of assessment. One stated that, "It is good to discuss in a group first, but at the same time, we disagree on some answers and the answer I would've written down if I were to do it myself is different from the group answer. Sometimes I feel like this is unfair because my answer, was actually right but instead I lost marks since it was to be a group effort."

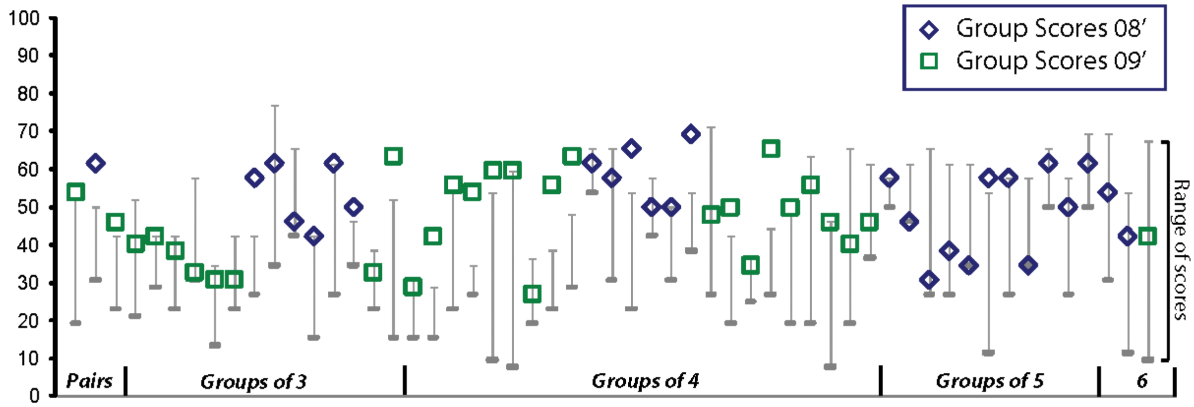
Limitations and Sources of Error

The methodology and use of the pre- and posttests instrument does allow for some notable sources of error. Primarily, the pre- and posttests was not rigorously validated, and as a result was "too easy," so learning gains, and individual and group results should be considered with caution. In 2009, Dohaney marked all of the tests, while in 2008, TAs also marked the posttest results. Even though a marking rubric was used, the results of these scores might be skewed, based on the expectations of the markers. Last, when considering the group size impact, it should be noted that statistically, we did not have enough group sizes of two ($n = 3$), or six ($n = 3$) to make accurate observations regarding their performance.

FACTORS THAT AFFECT GROUP WORK

Group learning has often been shown to be instrumental in student achievement and positive attitudes towards learning (Springer et al., 1999), but has some limitations. Our results from pre- and posttests showed that group learning was effective overall and indicated that group size is a factor that might affect group "success," but that group make-up was not a factor in this curriculum. The level of collaboration can be impacted by other factors such as the individually assigned "worth" of the group assessments, and TA attitude and behavior toward group work.

A. Group Size:
Pre-test results from 2008 and 2009

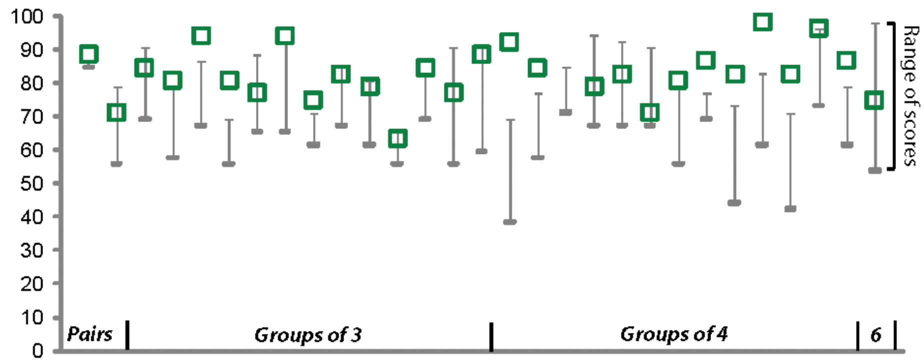


B. Pre-test statistics

*Group 'success' as defined by the group score > top student score (Michaelsen, L. K., Bauman Knight, A., & Fink, L. D., 2004)

Group Size	2	3	4	5	6
n=	3	17	21	11	3
Mean of group scores	53.8	44.6	52.8	48.3	46.2
Mean range	23.7	23.3	26.7	25.9	46.2
Mean (group - top student)	5.8	-3.1	1.2	-12.6	-17.3
Successful* (n)	3	5	11	1	0
Unsuccessful (n)	0	12	10	10	3
Successful (%)	100%	29%	52%	9%	0%

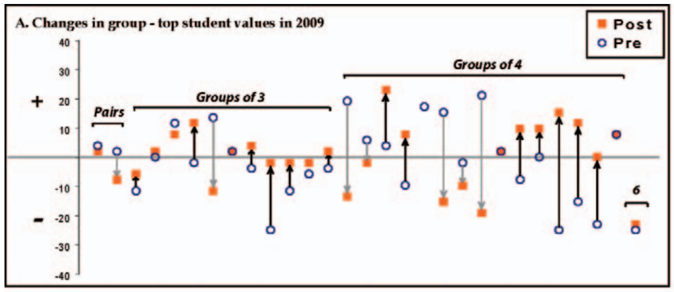
C. Group Size: Post-test results from 2009



D. Post-test statistics

Group Size	2	3	4*	6
n=	2	13	14	1
Mean of group scores	79.8	81.5	84.3	75.0
Mean range	12.5	17.7	23.6	44.2
Mean (group - top student)	-2.9	0.5	1.9	-23.1
Successful (n)	1	7	7	0
Unsuccessful (n)	1	5	6	1
Successful (%)	50%	54%	54%	0%

*Group size 4 had one group without a post-test score



B. Mean values for each group size, and overall changes in group collaboration

Mean of...	Group size 2		Group size 3		Group size 4		Group size 6		Overall	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Group - top student score	2.9	-2.9	-3.3	0.5	0.6	1.9	-25.0	-23.1	-1.6	0.1
Range*	1.9	9.6	38.5	23.1	46.2	42.3	N/A	N/A	46.2	46.2

*Statistically, group sizes of 3 and 4 will have a larger range due to higher n values

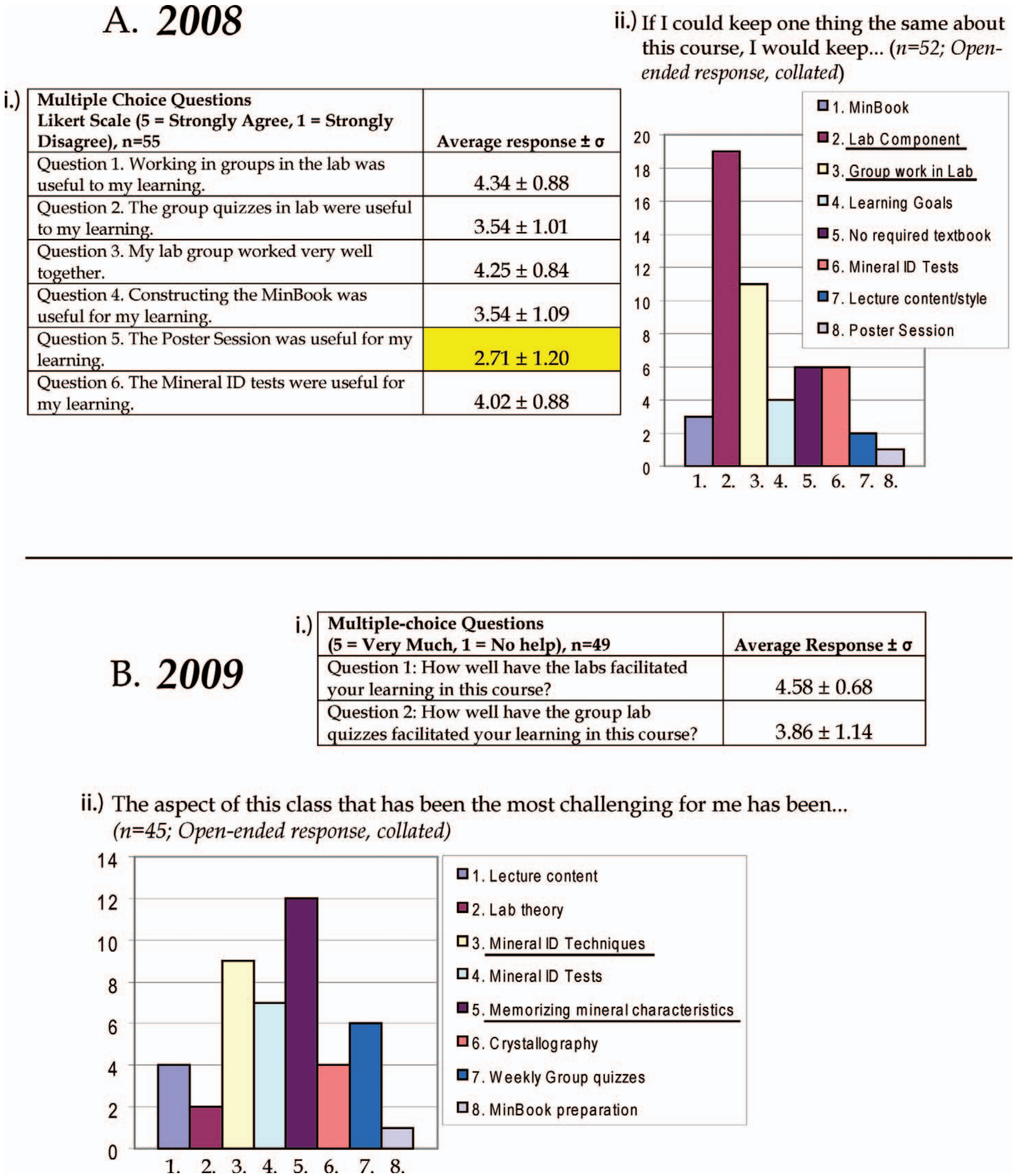
Change	Group size 2	Group size 3	Group size 4	Group size 6
Positive change	0	8	7	1
Negative change	2	2	5	0
No change	0	1	2	0

FIGURE 4: Group performance changes throughout the term in 2009. Scores from 2008 were omitted because of missing individual student posttest data. (A) Difference between the group scores and the top student scores at the beginning of the term (pretest) and the end of the term (posttest). Positive values indicate a "successful" group (Michaelsen et al., 2004). Arrows indicate the change throughout the semester. (B) Statistical table showing the means of the differential shown in (A) and the change over the term of positive collaborations versus negative collaborations. Overall, posttest differentials were consistently more positive, indicating collaboration is dominantly occurring in all group sizes. The group size of four is the most successful, illustrating the largest range, and largest changes, including some very negative changes. The group size of three showed incremental positive changes throughout the term [as indicated by the positive change category values in (B)], but did not achieve as many overall positive collaborative groups [as indicated by negative posttest values in (A)].

Group Size

Groups of different sizes can have different group dynamics, and this affects the level of collaboration achieved. We observed that when the groups were in disagreement, or if there were significant personality clashes, smaller groups created a mentality of "get on with it," while larger groups tended to segregate into pairs, becoming less collaborative. Research indicates that small groups (three and four students) have been successful for shorter assignments such as problem-solving exercises (Heller and Hollabaugh, 1992), while larger groups are more appropriate for complex, long-term and out-of-class assignments (Bales, 1967). Other research has shown that as groups become larger, fewer members actually participate in the group discussions (Bales, 1967), and in some cases display more off-task behavior (Maskit and Hertz-Lazarowitz, 1986); and as a result, members might feel less satisfied and less committed to the success of their group. We have found that small groups (three and four students) have been shown to be more effective than larger groups in this laboratory curriculum

←
FIGURE 3: Comparing group scores to individual student scores within the group. (A) A plot of the group pretest scores, with the range of individual student's scores sorted by group size along the x-axis. (B) A statistical table comparing mean group scores, mean range, mean (group comprising the top students) values, and the number of successful and unsuccessful groups for pretest scores, sorted by group size. (C) Same plot as in (A) for the 2009 posttest scores. (D) Same table as in (B) for the 2009 posttest scores. In pretest and posttest results, a group size of four is more successful for our laboratory curriculum.



A. *2008*

i.)

Multiple Choice Questions Likert Scale (5 = Strongly Agree, 1 = Strongly Disagree), n=55	Average response ± σ
Question 1. Working in groups in the lab was useful to my learning.	4.34 ± 0.88
Question 2. The group quizzes in lab were useful to my learning.	3.54 ± 1.01
Question 3. My lab group worked very well together.	4.25 ± 0.84
Question 4. Constructing the MinBook was useful for my learning.	3.54 ± 1.09
Question 5. The Poster Session was useful for my learning.	2.71 ± 1.20
Question 6. The Mineral ID tests were useful for my learning.	4.02 ± 0.88

B. *2009*

i.)

Multiple-choice Questions (5 = Very Much, 1 = No help), n=49	Average Response ± σ
Question 1: How well have the labs facilitated your learning in this course?	4.58 ± 0.68
Question 2: How well have the group lab quizzes facilitated your learning in this course?	3.86 ± 1.14

FIGURE 5: Graphs and multiple-choice questions illustrating positive student feedback collected from 2008 (A) and 2009 (B).

(five or six students), but more data are needed to validate this observation.

Group Make-up

Some studies indicate that the make-up of groups influences learning and collaboration. Some state that heterogeneous groups (where students are of mixed abilities, i.e., high and low achievers) are more beneficial than homogenous groups (Webb, 1997). Other studies indicate that heterogeneous groups with large differences in talent (e.g., a group containing a student of a much higher ability) might inhibit total group performance (Nihalani et al., 2010) and encourage dysfunctional behavior. To avoid negative group dynamics within heterogeneous groups, using peer evaluation can enhance a group's ability to work together by helping students identify group weaknesses and strengths in their abilities (Barron et al., 1998; Beichner et al., 2000), and helping them to relate to one another.

Regardless of group make-up, it is accepted that low-achieving students can achieve learning gains (Giuliodori et al., 2008; Macpherson et al., 2011) and best practices (Nihalani et al., 2010) from group work. However, our data did not indicate a significant association between heterogeneous and homogenous talent groups within this curriculum format.

Worth of Group Assessment

Increasing the marking value (or worth) of the group assessment could motivate some students to engage (Karau et al., 1993; Webb, 1997; Cortright et al., 2003) and thereby enhance the productivity of the group. However, it is also likely that increasing the worth of the group assessments could cause some students to resent the use of group work. Task or assessment worth is individually defined (Ryan and Deci, 2000; Eccles, 2005), and several students did indicate in the feedback surveys that they felt that group quizzes were an unfair way to assess their individual efforts.

TA "Buy In"

TAs should be more vigilant to noticing negative group dynamics such as disengagement and "freeloading." The attitude of the TAs can affect laboratory learning environments and communication of content to the students. Goertzen et al. (2009) found that TAs who "buy into" the method and style of teaching used are more likely to convey their respect for the material and the teaching process to the students, as well as learning more themselves. We have used weekly meetings with the TAs in order to review the mineralogy content being taught and troubleshoot any issues that might occur during the term. We have found these meetings to be invaluable for establishing positive, unified teaching strategies among our graduate students. Positive attitudes about the group learning strategy from TAs can help students accept this format more readily and foster a more successful learning environment.

CONCLUSION

Based on positive student feedback and increased learning gains, we will continue to utilize the current curriculum design for our Introductory Mineralogy course. Organization of learning material, use of customized projects, and group-learning strategies have all been shown to be successful in this laboratory format. Based on pre- and posttests results, group work led to better student performances individually and as groups. This course will limit the group size to three or four students, based on the results of this study, and we suggest that similar laboratory formats (e.g., Petrology or Introductory Geology) could also benefit from group learning.

Students continued to have difficulty with the amount of memorization that they believe is necessary for this course. Like all other descriptive sciences, mineralogy requires a detailed observational and textural vocabulary to describe and identify minerals. We can help our students by encouraging them to practice these skills together, so that the new vocabulary and mineral names become a part of their geological lexicon. Because using group assessment for this is not favored by some students, and if smaller class numbers are available, then paired learning might be a more positive learning experience for some. The opportunity for peer learning is invaluable to their development of social, practical, and intellectual skills that are needed in the "real world." By helping, practicing, and strategizing with each other, they can overcome the challenges that students face with understanding of mineralogical content.

CWSEI continues to assess this course (lecture and laboratories) as a part of its departmental effort to improve geoscience education (Carl Wieman Science Education Initiative, 2009). A copy of the laboratory materials and other content written and designed for this course is available from the first author.

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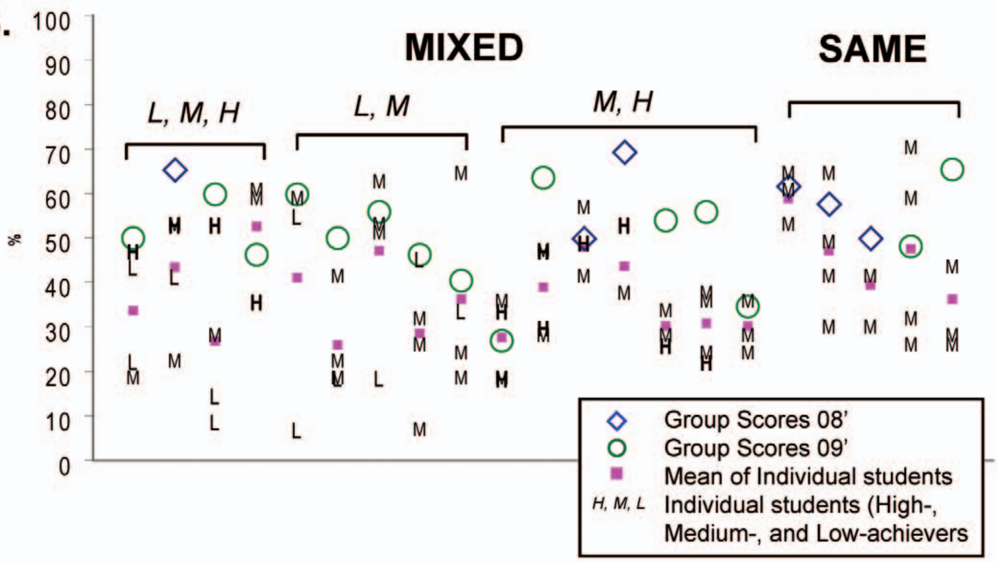
APPENDIX 1: EFFECT OF MIXED VERSUS SAME-TALENT GROUPS

In order to determine whether group work was more or less successful for differing talents (or intellectual abilities), we assigned students to categories based on their final course grades. The table in Fig. A(part A) shows the criteria by which students were assigned to these categories. Figure A(part B) illustrates the difference between group scores (in percentage) and the mean score of all the group members (high, medium, and low achievers) in a group size of four for pretest scores in 2008 and 2009. The table in Fig. A(part C) illustrates that in our study, there are no major differences between homogenous and heterogeneous groups.

A.

Year	n	Mean Course Grade (μ)	σ	Assigned Categories	n per Category
2008	112	69.65	8.37	Low (scores < -σ) = < 61.28% Medium (-σ to σ) = 61.28% – 78.03% High (scores > σ) = >78.03%	L = 18 M = 75 H = 19
2009	103	70.47	9.25	Low (scores < -σ) = < 61.22% Medium (-σ to σ) = 61.22% – 79.73% High (scores > σ) = >79.73%	L = 16 M = 72 H = 15

B.



C.

Same Talent Groups	2		3		4		5		6	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
n=	1	1	1	5	3	2	0	0	0	0
Mean Group Score (%)	62	46	62	47	56	57	-	-	-	-
Mean of Mean Student Scores	40	33	56	38	48	42	-	-	-	-
Mean of Top Students per group	50	42	77	52	58	58	-	-	-	-
Mean Range of Group	19	19	42	28	22	31	-	-	-	-

Mixed Talent Groups	2		3		4		5		6	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
n=	0	1	5	7	3	14	12	0	2	1
Mean Group Score	-	54	52	34	62	49	48	-	48	42
Mean of Mean Student Scores	-	36	42	28	45	35	48	-	48	36
Mean of Top Students per group	-	52	52	36	55	49	61	-	62	67
Mean Range of Group	-	33	22	17	21	29	26	-	40	58

FIGURE A: Effects of mixed or same-talent abilities on group and individual scores. (A) Grading criteria for which students were assigned into specific talent categories in 2008 and 2009. (B) Pretest scores of groups with four students in 2008 and 2009, sorted into their respective talent make-up. (C) Table showing that statistically, there is no major difference between homogenous and heterogeneous ability groups.