Engaging Engineering Students in Geoscience Through Case Studies and Active Learning

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ABSTRACT

This study reports on a case study–based curricular intervention designed to help undergraduate engineering students make connections between geoscience and its applications. Teaching through case studies resulted in a measurable and significant improvement in the confidence that students had in their ability to apply geoscience concepts in an engineering context. Before the intervention, students in the Bachelor of Science program in Mining Engineering at Colorado School of Mines struggled to solve problems using geoscience concepts in upper division courses. This motivated faculty to revise the required geoscience courses to better demonstrate how geoscience can be applied to solve engineering problems. There were three elements to the revision: each topic was introduced in an applied context, students gave case study presentations on geoscience in mining, and active learning techniques were employed during lecture sessions. In this paper, teaching materials are presented for a faculty-led case study, associated active learning exercises, and a student case study assignment. Student attitudes toward geoscience were surveyed using a one group pretest–posttest quasiexperimental design. At the beginning of the course, students who had previous encounters with applied geoscience had more positive attitudes toward geoscience ($p \leq 0.05$). Comparison of pretest and posttest responses showed significant improvement ($p \leq 0.05$) in three areas: students gained exposure to geoscience concepts, had increased confidence that they could provide concrete examples of applied geoscience, and were more willing to convince a friend or colleague that geoscience was important in mining. *© 2017 National Association of Geoscience Teachers*. [DOI: 10.5408/16-145.1]

Key words: case studies, active learning, engineering, attitudes

INTRODUCTION

It is critical for engineering students to connect foundational science concepts to their applications. This is the case for geoscience in mining engineering. Most mining engineering tasks rely on knowledge of geological processes, geological materials, and geological complexity, and Accreditation Board for Engineering and Technology (ABET)–accredited programs must prepare graduates "to have fundamental knowledge in the geological sciences including characterization of mineral deposits, physical geology, structural or engineering geology, mineral and rock identification and properties" (ABET, 2014). However, mining engineering majors at Colorado School of Mines have had difficulty using geoscience to solve engineering problems. In recent years, the geoscience components of the capstone Senior Design projects have been the weakest, and students have commonly displayed negative attitudes about geoscience and its relevance to engineering.

This contribution reports on the teaching materials and methods used to revise a geoscience course for mining engineers. The primary learning goal for the course was for students to use geoscience concepts to solve engineering problems. The present study examines how student attitudes toward geoscience were affected as students made connections between geoscience and its engineering applications. The intervention was designed around two premises: that students learn better when actively engaged in the learning process (Chickering and Gamson, 1987; Bonwell and Eison, 1991; Prince, 2004; Wieman, 2014) and that case studies, as a form of active learning, improve student attitudes and engagement with the material (Robbins, 1975; Klos, 1976; Bonwell and Eison, 1991; Kesner et al., 1997; Mustoe and Croft, 1999; Preszler et al., 2007; Armbruster et al., 2009). In the present study, a mineralogy, petrology, and ore deposits class formerly taught using traditional techniques was delivered to mining engineering majors in a revised form, with emphasis on active learning and case studies. Teaching materials are presented for a faculty-led case study, associated active learning exercises, and a student case study assignment used in the course (supplemental files 1–4; available in the online journal and at http://dx.doi.org/10.5408/16-451s1, http://dx.doi.org/10.5408/16-451s2, http://dx.doi.org/10.5408/16-451s3, and http://dx.doi.org/10.5408/16-451s4). The effects of this intervention on student attitudes were gauged using pretests and posttests modeled after two existing survey instruments: the Colorado Learning Attitudes about Science Survey (CLASS; Perkins et al., 2004; Adams et al., 2006) and a study on student attitudes toward statistics (Schau et al., 1995).

SUPPORT FOR CASE STUDIES AND ACTIVE LEARNING

Numerous studies have demonstrated that students learn better when they are actively engaged in the learning process (e.g., Chickering and Gamson, 1987; Bonwell and Eison, 1991; Prince, 2004; Wieman, 2014). Chickering and Gamson (1987) suggested that effective active learning involves more than listening to a lecture; students must be involved in higher-order thinking by tasks such as writing,

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discussing, or problem solving. In active learning exercises, students commonly receive immediate feedback from peers or instructors, to which Hake (2002) applied the term "interactive engagement." Prince (2004) proposed that active learning is based on two core elements: student activity in the classroom and student engagement.

A number of studies have gathered quantitative data to demonstrate that active learning makes a significant difference in science, technology, engineering, and mathematics (STEM classes; see, e.g., Redish et al., 1997; Hake, 1998; Laws et al., 1999; Yuretich et al., 2001; Beichner et al., 2008; Gaffney et al., 2008; Freeman et al., 2014). In one of the larger studies on active learning to date, Hake (1998) collected pretest and posttest data from 6,000 introductory physics students. The 62 instructors of these courses self-reported on the type of instruction used, and Hake (1998) showed that students in courses delivered with substantial interactive engagement showed more than twice the improvement of students in traditional lecture courses. In a recent metaanalysis of 225 studies of undergraduate STEM courses, Freeman et al. (2014) found that active learning methods substantially increased student exam scores and concept inventory performances; these methods also decreased failure rates.

In Bonwell and Eison's (1991) classic monograph on active learning in higher education, the authors point to case studies as one possible mechanism for facilitating active learning. They define case studies as real accounts of human experience based on real problems (cf. Fisher, 1978). In a manual for teaching materials science and engineering, Davis and Wilcox (2003) defined case studies as "student centered activities based on topics that demonstrate theoretical concepts in an applied setting." In the present contribution, case studies are viewed as a mechanism of active learning intended to illustrate concepts, provide real-world context, and stimulate student interest.

In science and engineering, numerous authors have reported on the use of case studies in the classroom to help students translate knowledge from theory to practice (e.g., Alic, 1977; Vesper, 1978; Henderson, 1978; Herreid, 1994; Cheng, 1995; Raju and Sanker, 1999; Bradley et al., 2002; Davis and Wilcox, 2003; Herreid, 2005; Camill, 2006; Yadav et al., 2007; Frisch and Saunders, 2008; Gallucci, 2009; Ponder and Sumner, 2009; Yadav et al., 2010; Goldsmith, 2011). Raju and Sanker (1999) showed that case studies are effective methods by which to expose engineering students to real-world scenarios that they may encounter in careers in engineering industries. Fry et al. (1999) described case studies as means of illustrating a main point or concept while simultaneously highlighting real-world context and complexity. Case studies help emphasize problem-solving skills and demonstrate to students that many problems have no "correct" answer (Romm and Mahler, 1986). Thus, case studies are also a possible means by which to introduce students to the gray areas of "engineering judgment." Previous studies have demonstrated that case study–intensive teaching improves student attitude, interest, and motivation in a subject relative to traditional approaches (Robbins, 1975; Klos, 1976; Bonwell and Eison, 1991; Kesner et al., 1997; Mustoe and Croft, 1999; Preszler et al., 2007; Armbruster et al., 2009). This study examines the impact of case studies on engineering student attitudes toward geoscience.

DEGREE CURRICULUM

Ten credits of geoscience are required in the 139.5-credit Bachelor of Science in Mining Engineering degree at Colorado School of Mines. Of these credits, 4 are delivered in a general geoscience course, and 6 credits are delivered across two courses geared toward mining engineering students: Earth Materials and Resources for Mining Engineers (EMR), and Structural Geology for Mining Engineers. This paper focuses on EMR. In the current curriculum, this 4-credit course covers hand specimen mineralogy; igneous, metamorphic, and sedimentary petrology; geological engineering; ore deposits; and mineral exploration. Students following the recommended course sequence take EMR in the junior year. The lecture portion of the class meets twice per week for a 50-min session and a 110-min session. Before the intervention described here, lectures were delivered in the traditional didactic style using PowerPoint slides, with student work conducted individually.

THE CURRICULAR INTERVENTION

In 2015, the lecture component of the EMR course was redesigned with the aim of helping students make connections between geoscience and mining applications and thus improving student attitudes toward geoscience. There were three components of the intervention: (1) geological concepts were taught in the context of case studies presented by the faculty, (2) teams of students gave case study presentations, and (3) active learning exercises were incorporated into class meetings. Each of these components is described in detail in upcoming sections.

The intervention was based on the hypothesis that student attitudes could be improved by engagement in the process of learning and demonstration of the relevance of geoscience using a case study–intensive curriculum. Table I shows learning outcomes for the course, how these learning outcomes were aligned with the components of the intervention, and the survey questions that were targeted to address learning outcomes.

The class was team-taught by two faculty members in the Department of Mining Engineering. The author served as the primary instructor in the course and specializes in mining geology. The department head played a supporting role by attending class meetings, answering student questions during breakout sessions, and leading several class meetings in her areas of expertise (geological engineering in heavy construction and tunneling). The two faculty members shared responsibilities for informally monitoring the effectiveness of the class activities, and this task was greatly facilitated when an extra faculty member was present in the classroom.

In lieu of a traditional introductory geoscience textbook, students were assigned reading from *Mineral Exploration and Mining Essentials* (Stevens, 2011), as well as chapters from classic texts in geological engineering (e.g., Terzaghi, 1946). The Stevens (2010) textbook provides a survey of general physical geology, structural geology, petrology, ore deposit geology, and mining geology for nongeoscience professionals in the mining industry. All of the geoscience concepts introduced in the book are explained in the context of their relevance to mining engineering and mining geology. The chapters provided from geological engineering textbooks

TABLE I: Alignment of student learning outcomes, case studies, active learning techniques, and survey questions.

Course Learning Outcome		**Methods for Course Learning Outcome**		**Part B Survey Questions**
1. Incorporate geological considerations into an engineering design		Active learning (in particular design exercises)		9, 16
2. Improve attitudes toward geoscience		Active learning (in particular, field excursions), faculty case studies		1, 2, 3, 6–11
3. Provide concrete examples of geoscience in mining		Faculty case studies, student case studies		12–14
4. Explain why geoscience is important in mining		Faculty case studies, student case studies, active learning (in particular, minute paper, think–pair–share, small-group discussion)		12, 15
Topical Learning Outcome		**Faculty Case Study**	**Active Learning Technique**	**Part B Survey Questions**
Weeks 1–4	1. Describe the physical and chemical characteristics of an individual rock or soil type	Mining history of Golden, Colorado	3 field excursions	4–6, 12–14
Weeks 1–4	2. Collect and analyze field data to provide evidence for how rocks and minerals are formed	Mining history of Golden, Colorado	3 design exercises, reflection, small-group discussion	6, 9, 16
Week 5	3. Predict how excavation might vary across a site with multiple rock types	Tunneling in Rochester, NY	Think–pair–share	16
Week 6	4. Propose which geological processes were active to produce the geomorphology at a given site	Slope stability at Yungay Viejo	Small-group discussion	4–6
Weeks 7–10 and 12	5. Predict the physical characteristics of an ore deposit based on a geological deposit model, and identify how these characteristics impact mining activities for the following deposit types: laterite, uranium, coal, BIF, placer, porphyry, epithermal, skarn, VMS, orogenic, Carlin type[1]	Numerous case studies, including Suriname bauxite, Pennsylvania coal, Yukon placer, Argentina silver, Pebble Alaska copper, Nevada gold	Collaborative learning group, design exercise, jigsaw, minute paper, partner quiz, reflection, small-group discussion, think–pair–share	16
Week 11	6. Propose a mineral exploration program based on site and deposit-type characteristics	New Zealand porphyry and epithermal exploration	Design exercise	16
Weeks 13–16	7. Predict possible environmental issues at a site based on an understanding of the geological characteristics of the ore deposit style	Pebble Alaska	Minute paper, think–pair–share, small-group discussion, role play	14, 16

[1]BIF = banded iron formation; VMS = volcanogenic massive sulfide.

TABLE II: Detailed class schedule, weeks 14–15.

Week 14	
Monday (50-min class)	○ Student case study presentation and peer evaluations (10 min; supplemental files 1 and 2) ○ Open discussion of student case study presentation (5 min) ○ Minilecture (30 min; supplemental file 3) ▪ Environmental considerations for mining, Pebble controversy ▪ Active learning exercises interspersed throughout class meeting (supplemental file 3) • Minute paper: Why might it be important to think beyond the block model when planning or operating a project? • Think–pair–share: What are some examples of possible environmental consequences for each of the six listed mining methods? • Small-group discussion: In teams of three, pick one of the six mining methods and discuss potential reclamation methods for the atmosphere, biosphere, geosphere, and hydrosphere. Report back to the class in 10 min. ○ Assign reading homework ▪ Students were randomly assigned one article on acid mine drainage to read from a list of four. Two of the articles were short scientific review papers, and two of the articles were opinion pieces (one pro- and one antimining).
Wednesday	Thanksgiving holiday, no class
Week 15	
Monday (50-min class)	○ Student case study presentation and peer evaluations (10 min; supplemental files 1 and 2) ○ Small-group discussion on assigned reading homework (40 min total) ▪ Learning (~20 min) • Students meet with three or four other students who have read the same article, addressing the following questions in discussion: 1. From what perspective and by what type of authors is the article written? 2. What are the five main points your classmates should learn from this article? 3. What are the implications for the proposed Pebble Mine? ▪ Teaching (~20 min) • Teams are reassigned by numbering off so that each team has a member who read a different article • Each person shares responses to #1–3 with their new team
Wednesday (110-min class)	○ Student case study presentation and peer evaluations (10 min; supplemental files 1 and 2) ○ Acid mine drainage evaluation (100 min; supplemental file 4)

were selected to help students connect the geoscience content in the course to prior engineering knowledge.

There were 30 students enrolled in the 2015 course: 25 juniors and 5 seniors. Only 5 of the students were women. All of the students had previously taken a general geoscience course at Colorado School of Mines or elsewhere. Fourteen of the students had previously held engineering-related internships, but there was no significant correlation between academic status and internship experience. Other demographic data, such as ethnicity and age, were not surveyed.

Class Structure

The 50-min class meetings were conducted according to the following structure: class began with a student case study presentation and peer evaluations. Then, a faculty-led case study was either introduced or continued from a previous week, in one of two modes: lecture format with interspersed active learning exercises or exclusively via active learning exercises. The 110-min class meetings also began with student case studies and peer evaluations, typically followed by a more extended active learning exercise tied to the week's faculty-led case study. Several 110-min class meetings were composed of only active learning exercises such as field trips, and three class meetings were devoted exclusively to exams. The structure of three typical class periods is outlined in Table II, with further detail provided on the mechanics of the student and faculty case studies in subsequent sections.

Active learning was defined based on Prince (2004), comprising techniques that introduced activity into the lecture period and promoted student engagement. All of the techniques used in the EMR course (Table I) are well studied, and evaluations of the efficacy of each technique are not provided here. The active learning techniques employed in each class session were selected in advance to provide scaffolding and formative assessment for the learning outcomes listed in Table I. Selection was based on Bonwell and Sutherland's (1996) active learning continuum framework, primarily focusing on the first two continua of task complexity and course objectives, with less emphasis on classroom interaction and student experiences.

On the first day of class, students were informed that EMR would be an active learning–intensive course, comprising small-group discussion and other activities during the lecture period, in addition to short sessions of traditional lecture. The faculty also explained that active learning takes student effort and can sometimes be uncomfortable. Each student was asked to set a goal of speaking in class at least once per day during activities to obtain full credit on the 10% participation grade. The faculty also prepared the students for what to expect during the semester by incorporating several simple practice activities into the first class meeting. Because most courses in the degree program currently

TABLE III: Student case study presentation topics.

Salt dome geology for mining and petroleum exploration
Landslides caused by spoil pile collapse: an example from coal mining in the Philippines
Rockbursts in the deep underground at the Sudbury mine, Ontario
Seafloor mining of hydrothermal vent metals in black smoker deposits
Geology and slope stability at the Robinson Mine, NV
Slope stability at the Bingham Canyon Mine, UT
Layered mafic intrusions at the Mogalakwena platinum mine
Acid mine drainage remediation at the Pennsylvania Mine, CO
Geology of Florida's aggregate mines
Geology and geophysics at the Cargill Salt Mine beneath Lake Erie
Surface subsidence above the Signal Peak coal mine, MT
Geological causes of the Northparkes Mine air blast, New South Wales, Australia
Geophysical exploration for IOCG deposits at the Carajas Mineral Province, Brazil
Slope stability of the Garzweiler coal mine expansion pit, Germany

[1]IOCG = iron oxide copper gold.

comprise traditional lectures and separate hands-on laboratory sessions, these were important steps to help the students prepare for an intensive active learning experience.

Student Case Study Presentations

Student case studies were among the central exercises in the EMR course. The assignment was to identify and present an example of a geological problem at an active mine or excavation site in a 10-min PowerPoint (or similar) presentation for 15% of the course grade. Students self-selected into teams of two or three, and each team picked a presentation slot from a list of available dates. Class time was allotted for one team to present a case study at almost every class meeting. Each team presented one case study during the semester. The teams identified their own topics and worked on the presentations as homework. The presentations were required to include a basic description of the site's geology, the nature of the problem, and how it was addressed or solved. This exercise could be easily adapted for other courses by adjusting the assignment to focus on geological problems as applied to the environment, geological hazards, civil infrastructure, etc. No list of potential topics was provided. Instead, students were encouraged to gather information from news, scholarly articles, former internship mentors, faculty members, alumni, and other industry professionals. The presentations were distributed across the semester so that some class time was spent with students at the podium every week. All students in the audience participated in peer review of each presentation.

Students were given the case study assignment and rubric (supplemental file 1) and the peer evaluation form (supplemental file 2) once teams were formed in the first week of class. Then, the two faculty members presented example case studies developed from their own material using the format given in the assignment to illustrate the content and mechanics of a fully satisfactory versus an incomplete presentation. The first example was "Highwall Failure at the Gold Quarry Mine, Nevada," which focused on recent slope stability issues in the active open pit that were caused by mining through a fault plane parallel to the slope of the pit wall. The second example, "Rock Tunneling in Rochester, New York," documented the variation in tunnel boring machine penetration rate caused by excavation through different types of sedimentary rock. The first presentation fully addressed every item on the rubric, whereas the second presentation was deliberately incomplete, lacking citation of sources, a location map, and a description of how the problem was solved. The students practiced evaluating these presentations using the peer evaluation form.

Teams developed and presented case studies on topics ranging from dramatic events such as rock bursts and landslides to descriptions of how geological constraints influenced mine design, development, or reclamation (Table III). The students enjoyed the opportunity to research and become the experts on a particular case study. Because they gathered their case study information from external sources and other mentors, there was more diversity of examples than the two course instructors could provide. Although public speaking was more comfortable for some than for others, there were no complaints about the assignment. The students were generally supportive of one another, providing constructive criticism on the peer evaluation forms with occasional gentle ribbing of friends on other teams. It worked well for the students to practice conducting peer evaluations of the two example presentations given by the faculty, and this gave the students the opportunity to study the rubric and required presentation components.

There were a few potential areas for improvement of this exercise. Although there was no repetition of specific case studies, there was more repetition in geoscience concepts than the instructors had envisioned: 5 of the 14 presentations were examples of slope stability or mine collapse. This was likely because most of the students were concurrently enrolled in Rock Mechanics. In one sense, it could be considered a success that students were able to connect concepts between the two courses, but it became tedious for the audience to listen to repeated explanations of the same fundamental concepts as applied to similar scenarios. Faculty using a similar exercise at other institutions should be forewarned that students might be inclined to use examples already discussed in or made obvious by concurrent courses; this could be good or bad depending on the learning outcomes intended for the exercise. Another challenge came with scheduling of the presentations. Teams signed up for a timeslot that seemed convenient at the beginning of the semester, but most waited to choose a topic until the presentation date was nearing. Depending on when the presentations were scheduled in relation to course topics, not all teams had the background to present the case studies they were interested in, so the faculty members had to provide additional support to prepare them. Better alignment of student presentations with the course schedule might enhance the building of connections between the science concepts and their applications.

Faculty-Led Case Studies

The major geoscience concepts in the course were introduced in the context of an applied example from mining or the related fields of civil engineering, underground construction, metallurgy, and environmental engineering. Although giving real-world context for geological concepts is by no means a new teaching technique, serious effort was made to provide concrete examples of the lesson topic's applications at the outset. The real-world example was always presented first, and then the supporting science was introduced, rather than building up the geological background and subsequently introducing an application for the concept. Examples ranged in scope from brief vignettes to extended case studies that encompassed several lecture sessions and several topics. The case studies were presented in various ways, including photographs and maps in lecture slides, sketches on the whiteboard, creative-thinking problems during group or individual work, and oral histories presented for discussion and reflection. Examples were developed from classic case studies in mining, in response to questions asked by students, from the faculty members' collective experience in professional roles in industry, and from applied research projects.

The Pebble case study illustrates how real-world examples were used in the classroom (Tables I, weeks 7–12 and 13–16, and II). This case study could be used to teach a range of topics, in addition to ore deposits and mining, including environmental geology, geochemistry, and science policy. Pebble is a controversial proposed mining project in the Bristol Bay region of Alaska. Pebble is one of the world's largest gold, copper, and molybdenum porphyry-style deposits, but it is located in a seismically active area in the headwaters of a renowned salmon fishery. If a large seismic event were to occur, it is possible that acidic or metal-rich mine waters could be released into the salmon habitat. Whether the mine could be designed to prevent such an incident is a subject of great debate. A case study of the Pebble deposit was developed to serve as the context for three topics and associated active learning exercises: ore deposit geology, acid mine drainage, and environmental baseline studies. The geology of the porphyry-style mineralization at Pebble was introduced in a short lecture and active learning exercises in week 10. The class activities for weeks 14–15 are shown in Table II: students learned about the environmental context for the Pebble controversy in a short lecture and associated active learning exercises (supplemental file 3), read about acid mine drainage, engaged in small-group discussion, and conducted an acid mine drainage evaluation for Pebble (supplemental file 4).

In the acid mine drainage evaluation, students conducted calculations to determine the acid-generating and acid-neutralizing potential of the rocks that host the ore at Pebble. The students were asked to evaluate whether their results suggest a risk of acid mine drainage and to propose what other geological, environmental, and social factors should be considered when determining whether the deposit should be mined. This exercise is a unique opportunity for students to work with actual data that would not normally be available for educational use. Mining companies are not legally required to release baseline study data to the public, but when Pebble was under consideration for development by the mining company Anglo American PLC, the company released all of its environmental baseline data for public review (https://pebbleresearch.com/download/). Faculty members using this exercise might want to ask students to separate prior opinions from results generated from the dataset, because some students may have preconceptions about what the data should indicate. Results may vary among students depending on the subset of drill-hole samples selected for the calculations. Some students may conclude from their calculations that the ore is acid generating, and others may conclude that the ore is acid neutralizing. This lack of consensus generates an opening for discussion on sampling, statistically valid sample sizes, and how to make engineering and policy decisions in scientific gray areas.

ASSESSING THE INTERVENTION

The effectiveness of the intervention was examined with a one group pretest–posttest quasiexperimental design. The following sections describe the survey instrument and the pretest and posttest results.

Survey Instrument

The survey instrument (supplemental file 5; available in the online journal and at http://dx.doi.org/10.5408/16-451s5) composed of two sections: Part A, with 11 free response and dichotomous questions, followed by Part B, with 16 rating questions using a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Part A was designed to gather general information, including progress toward degree, courses taken, qualitative evaluations of student interest in the introductory geology course and the EMR course, and prior internships or work experience in mining engineering or related fields. Part A was only given in at the beginning of the course, because changes were not anticipated in the descriptive information about student backgrounds and past activities. Part B was given at the beginning of the course and the end of the course. Anonymous pretest and posttest responses were matched for individual students using self-assigned pin numbers confidential to each student.

The Likert questions were modeled after validated survey instruments in two previously published studies: the CLASS (Perkins et al., 2004; Adams et al., 2006), and a study on student attitudes toward statistics (Schau et al., 1995). CLASS was designed to evaluate student attitudes toward learning physics, as well as student beliefs about physics, and it has subsequently been adapted for use in biology and chemistry. CLASS also includes questions that test concepts and learning styles, which were not included in the present study given the focus on student attitudes. Selections from CLASS such as "I think about the physics I experience in everyday life" and "Reasoning skills used to understand physics can be helpful to me in everyday life" were incorporated directly by substituting "geology" for "physics." The survey of Schau et al. (1995) was originally designed to test interest, affect, and attitudes about the relevance and usefulness of statistics. Several of these questions were adapted to target these factors in the present study. For example, "Statistical skills will make me employable" was adapted to "The reasoning skills I learn in geology can help me in my career" and "The geological concepts I learn in geology will help me in my career." Table I shows how survey questions were aligned with learning outcomes for the course. The focus of this

TABLE IV: Summary of survey responses and Mann-Whitney *U*-test results.

Survey Part A	Yes out of 30				*Z*-score	*p* (two tail)
A4. Did you take GEGN 101 or a similar introductory Earth Science course?	30					
A5. Did you find this course interesting?	26	Association with A9:			2.65	<0.01
A7. Did you find this class important?	25	Association with A9:			2.02	0.04
A9. Have you had an internship or work experience in mining engineering or a related field?	14					
Survey Part B	**Premedian**	**Postmedian**	**Premode**	**Postmode**	***Z*-score**	***p* (two tail)**
B1. I find geology interesting.	4	4	4	4	0.43	0.67
B2. I find geology confusing.	2	3	2	3	0.98	0.33
B3. I find geology intimidating.	2	3	2	3	0.67	0.50
B4. I have previously been exposed to big-picture geological concepts.	4	4	4	5	1.38	0.17
B5. I could explain some of the big-picture geological concepts that I have previously learned.	3.5	4	4	4	4.04	<0.01
B6. I think about the geology I experience in everyday life.	4	4	4	4	0.92	0.36
B7. The reasoning skills I learn in geology can help me in everyday life.	3	4	3	4	1.53	0.13
B8. The reasoning skills I learn in geology can help me in my career.	4	4.5	4	5	0.38	0.70
B9. The geological concepts I learn in geology will help me in my career.	5	5	5	5	0.84	0.40
B10. I believe that my time spent learning geology could be better spent on other topics.	2	2	2	3	1.02	0.31
B11. If I had plenty of time, I would take a geology class outside of major requirements for fun.	3	4	3	5	1.39	0.16
B12. My opinion is that geology is important in the field of mining.	4	5	5	5	0.80	0.42
B13. I have previously been exposed to geology as applied to mining.	3	2	2	2	0.73	0.47
B14. I can provide concrete examples of the importance of geology in mining.	4	5	3	5	3.70	<0.01
B15. I can convince a friend or colleague that geology is important in mining.	4	4	3	5	2.85	<0.01
B16. If I were to design a mine plan, I would think about the geology at the project site.	4	5	5	5	1.36	0.17

assessment was on student attitudes, although future studies are planned to examine the impact of the curricular revision on comprehension and application of geoscience concepts.

Survey Results

Dichotomous survey questions and Likert items were treated as ordinal data (e.g., Lovelace and Brickman, 2013). Mann-Whitney *U*-tests showed significant positive associations ($p \leq 0.05$) between internship experience and interest in the prior geoscience course and between internship experience and perceived importance of the prior geoscience course (Table IV). Several of the survey questions demonstrated that students had strongly positive attitudes to geology at the start of the course: For 8 of 16 questions, the presurvey mode was $\geq$4 of 5. Changes were observed between modes of pretest and posttest results for 9 survey questions (Fig. 1). Mann-Whitney *U*-tests demonstrated that improvement was significant for 3 survey questions at $p \leq 0.05$ (Table IV): exposure to geoscience concepts, ability to provide concrete examples of geoscience applications in mining, and ability to convince a friend or colleague of the importance of geoscience in mining.

DISCUSSION

The active learning and case study–intensive curriculum presented here was implemented to improve student attitudes toward geoscience and demonstrate how the course material was relevant to engineering. The Pebble

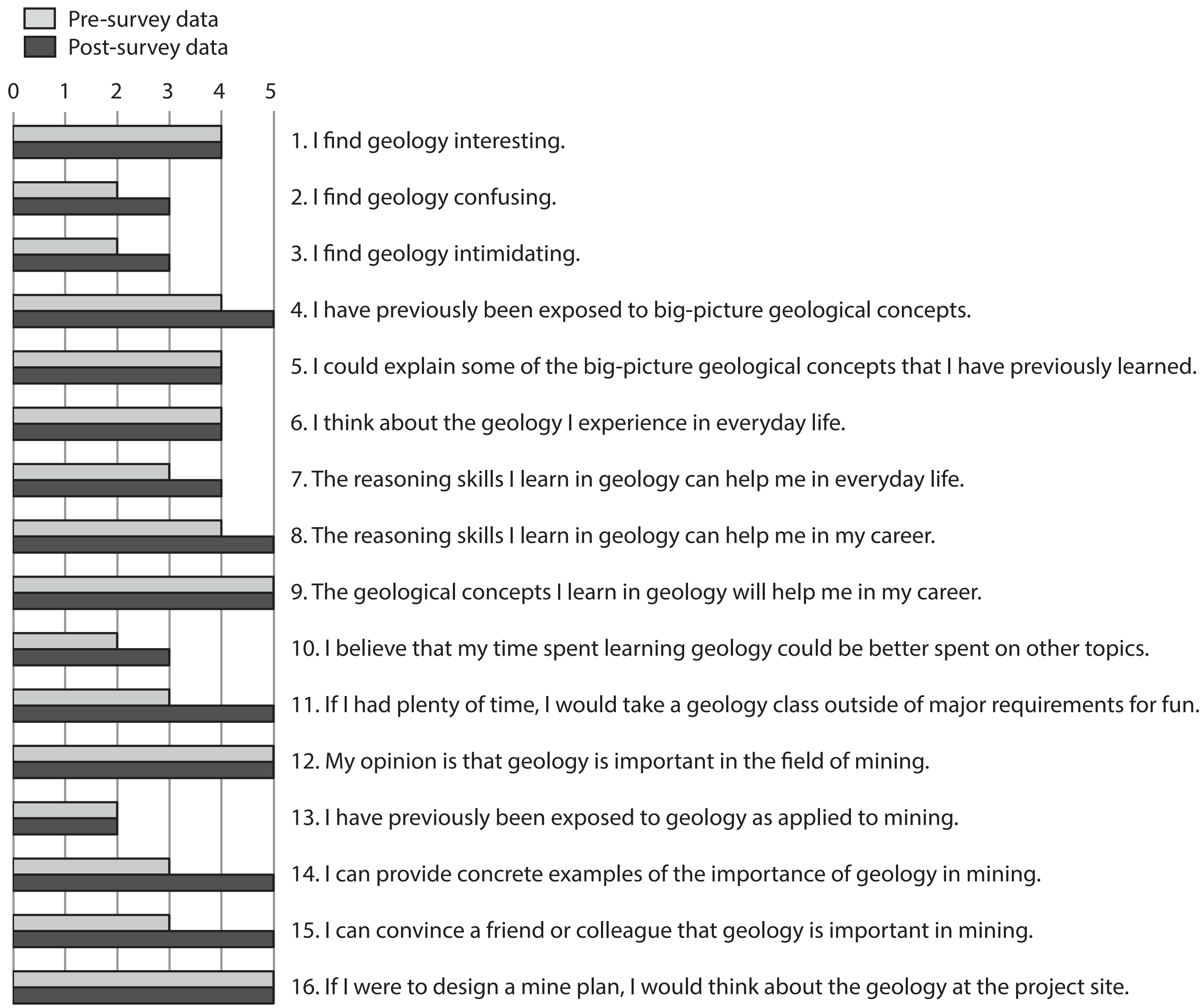

FIGURE 1: Modes of Likert-scale pre- and postsurvey data.

example is given to show how faculty-led case studies were used to teach geoscience concepts in real-world context. The student case study assignment gave students the chance to investigate how geoscience could be applied. Because the assignment included a class presentation, students in the course were exposed to 14 additional examples of applied geoscience from student case studies. Active learning enabled students to practice building connections between geoscience and mining at a range of cognitive levels, as demonstrated by the acid mine drainage assignment and the shorter exercises included in the introductory Pebble lecture.

Results from several of the pretest questions indicated that initial attitudes toward geoscience were more positive than expected, leaving little room for statistically significant improvement. This may be a function of the high percentage of students who had previously held internships. Previous encounters with applied geoscience in the context of an internship were associated with more positive initial attitudes.

Students made statistically significant gains in three areas during the course: exposure to geoscience concepts, confidence that they could provide concrete examples of applied geoscience, and willingness to convince a friend or colleague that geoscience was important in mining. These results are consistent with previously published studies suggesting that case studies and active learning have a positive impact on student attitudes and engagement. With a larger dataset, it would be interesting to compare the impacts of the curricular changes on student attitudes between those who had previous internship experience and those who did not. It seems likely that the case study–intensive curriculum would have a greater impact on students with no prior exposure to applied geoscience, in comparison to students who had previous internship experience.

This study did not collect data on other educational outcomes such as conceptual learning, and as such, interpretations cannot be drawn beyond the impact of the intervention on student attitudes. Although the method presented here was effective, within the context of this study it is not possible to determine whether the combined case study and active learning–intensive approach was more effective than the traditional didactic approach or other pedagogical methods. It is also not possible to evaluate whether case studies and active learning techniques played equal roles in influencing student attitudes. To assess the relative impacts of these two approaches, two nonoverlapping delivery methods would need to be designed and compared to a control group course: one involving case studies delivered in the traditional didactic manner and one involving active learning without case studies.

CONCLUSIONS

The combined approach of an active learning classroom environment, real-world context for each concept, and student case study assignments enabled students to build connections between foundational science concepts and their engineering applications. The survey data suggest that this approach helped improve student attitudes toward geoscience. The Pebble case study, acid mine drainage evaluation, and student case study assignments are presented here for use in other courses. These specific exercises could be used to teach a range of geological concepts in an applied context. A similar approach of case studies and active learning could be developed for teaching other science topics in applied contexts. Future studies should investigate the impact of this type of intervention on comprehension and application of science concepts.

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