Chemistry Education for the Geosciences: Perceptions of Importance and Relevant Knowledge

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The role of chemistry in preparing geologists is not well defined or quantified. Chemistry content and coursework can present challenges and misconceptions that act as barriers for many students (Anderson and Libarkin, 2016; Barbera, 2013). The American Geosciences Institute (AGI) *Geoscience Handbook* (Carpenter and Keane, 2016) identifies key chemistry concepts and skills for the geosciences. With the diversity of career paths in the geosciences, universal chemistry training guidelines for all is impractical. Our goal is to elucidate geologists' perceptions of the foundational chemistry knowledge students need for a geoscience degree. We use the term "geosciences" throughout, reflecting the range of degree programs that would align with content outlined in the AGI handbook. Results from this pilot survey can inform curricular choices, course content, and program requirements for geology students.

MATERIALS AND METHODS

The pilot survey was developed to investigate the perceived importance of chemistry, the amount of chemistry preparation, and the chemistry skills needed for a geoscience degree (see Supplemental Material[1] item 1). The first section contained 18 items assessing perceptions of the importance of chemistry and chemistry preparation. Participants responded to statements such as, "Chemistry is an integral component of a geoscience student's undergraduate degree," using a five-point Likert-style scale ranging from "strongly disagree" (1) to "strongly agree" (5). The second section asked participants to report how many semesters of chemistry they perceive are necessary for a geoscience student to be successful in a bachelor's degree, master's degree, Ph.D., industry career, and academic career. A third section asked participants to rate how often (e.g., "never," "seldom," "often," or "every day") they think each concept or skill is "necessary for an undergraduate degree in the geosciences." The list of chemistry skills was selected from topics in the AGI *Geoscience Handbook*, which was developed from input from 240 geoscience experts (Carpenter and Keane, 2016). We added skills to include aqueous, gas, and solid materials chemistry. For example, in the AGI handbook, it states, "Apply properties of elements to solid earth materials," and we added two parallel items about aqueous chemistry and gases. Demographic information was collected on the final page of the survey to determine participants' level of expertise (e.g., undergraduate, graduate student, or professional). For content validity, two geochemistry faculty reviewed the content and language of the items.

We distributed the survey in the exhibit hall at the 2018 Geological Society of America (GSA) Annual Meeting in Indianapolis, Indiana (5,625 attendees), USA, through the Geocognition Research Lab (GRL) Booth hosted by Michigan State University (MSU). Incentives for completion of the survey were snacks (e.g., candy bar, bag of chips). A total of 146 surveys were completed, from which we omitted incomplete surveys and participants whose expertise fell beyond the categories described below (e.g., K–12 teachers). Surveys from 108 participants were grouped based on self-reported current position as: (1) undergraduate students (n = 41); (2) graduate students (e.g., M.S. or Ph.D.) (n = 36); and (3) experts (i.e., industry or academia professionals) (n = 31).

Reliability analyses performed using SPSS Version 26 confirmed the latent structure of the survey dimensions for importance and preparation, and good reliability (α = 0.759). Parametric statistics assumptions were checked (Sullivan and Artino, 2013). The "preparation" sub-scores were normally distributed, and the "importance" sub-scores skewed positive and leptokurtic. Total sub-scores were computed for "importance" and "preparation" statements by summing the Likert-style values (1 for "strongly disagree" to 5 for "strongly agree"). A one-way ANOVA compared the means between the three expertise groups (e.g., undergraduates, graduate students, and faculty or professionals). A Pearson's Chi Square analysis compared the group means for the number of semesters needed for the various geoscience degrees or career paths (e.g., B.S., M.S., Ph.D., industry, academia). To analyze participants' ratings of the skills necessary for undergraduate geoscientists, we totaled the number of participants from each expertise group responding at each level of frequency (Fig. 1). Complete data files are available in Supplemental Material item 2 (see footnote 1).

RESULTS

There was no significant difference in ratings for importance statements between the three expertise groups (F[2,97] = 0.283, p = 0.754), nor for the preparation statements (F[2,97] = 0.409, p = 0.665). Participants from all groups agreed that two semesters of chemistry are necessary for a B.S. in the geosciences (X^2 [8, N = 108] = 7.844, p = 0.449) and four are necessary for a geoscience career in industry (X^2 [8, N = 98] = 5.943, p = 0.654) or academia (X^2 [8, N = 102] = 14.038, p = 0.081). Undergraduates and experts differed on how many semesters of chemistry are necessary for an M.S. (X^2 [8, N = 99] = 23.171, p = 0.003) or a Ph.D. (X^2 [8, N = 99] = 23.020, p = 0.003). Experts reported that three semesters are

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[1]Supplemental Material. Item 1: original survey administered in this study. Item 2: original data from this study. Go to https://doi.org/10.1130/GSAT.S.20449821 to access the supplemental material; contact editing@geosociety.org with any questions.

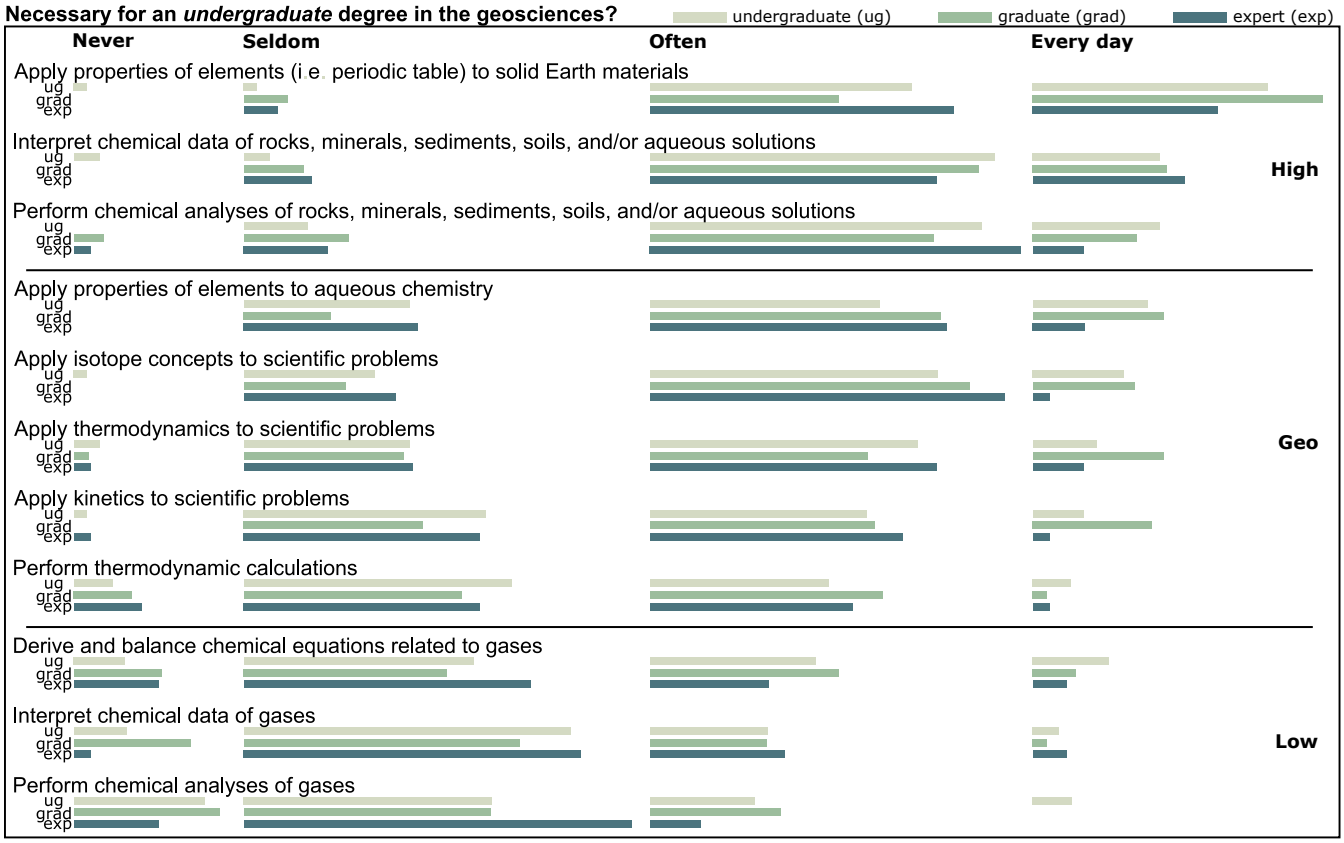

Figure 1. Participant ratings of 11 of the 20 chemistry-related skills surveyed, including three highest and lowest, and five most geoscience relevant topics.

needed for an M.S. or Ph.D. geoscience degree, while undergraduates reported an average of four courses for these degrees. Note: We did not ask which chemistry courses should be required.

Figure 1 shows 11 of the 20 skills participants rated. For visual clarity, we only included the three highest- and three lowest-rated skills and five skills particularly relevant to the geosciences (e.g., isotopes). Participants agreed that the most important skills (labeled "high") related to applying properties, interpreting chemical data, and performing analyses of solid Earth materials. The lowest-rated skills were those involving gases. Graduate students and experts indicated they "often" engage in "applying isotope concepts to scientific problems" (n_{ug} = 7 of 41; n_{grad} = 22 of 36; n_{exp} = 21 of 31 (ug—undergraduate; grad—graduate student; exp—professional).

DISCUSSION AND NEXT STEPS

Overall, the three expertise groups shared general consensus regarding the importance and amount of chemistry necessary for the geosciences. Participants ranked chemistry content and skills associated with aqueous and solid chemistry higher than those associated with gas chemistry (Fig. 1). Applying isotopes to scientific problems ranked highly but is not a focus of most general chemistry courses. Second semester general chemistry does focus on thermodynamics, which participants noted they use often.

The results of this pilot study provide preliminary perceptions of the type and quantity of chemistry content geologists value for a geoscience degree. However, the survey instructions did not define the parameters of a "geoscience degree." GSA attendees draw from 22 scientific Divisions, and the survey participants represented this perspective. We did not analyze participants' discipline of expertise. The findings suggest tutorials focused on improving geoscience students' basic chemistry skills, similar to "The Math You Need" tutorials (Wenner and Baer, 2015), may be useful for topics of high importance but absent from the general chemistry curriculum. Targeted training can alleviate barriers associated with learning chemistry as a geoscience major.

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