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Making Connections to Real Data and Peer-Review Literature: A Short Soil Exercise in a Geochemistry Class

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ABSTRACT

A class exercise was designed for a college-level geochemistry class to promote inquiry and student participation. In this exercise, real soil data available online was analyzed to evaluate geochemical associations among different soil orders and as a screening tool for anthropogenic metal contamination. Students were asked to read a peer-reviewed research article and use the methods in it as a model for analyzing their dataset. The exercise provided a setting to review and reflect on the changes that rocks undergo to produce soils, with ion substitution and formation of clay minerals as key steps in this process. Both active learning and cooperative learning were involved. Students made decisions about which path to take toward reaching a common goal; they first worked independently and later discussed the results as a group, comparing between three statistical methods applied with the data with respect to their advantages and limitations. The real-life dataset exposed students to the common shortcoming of having less-than-ideal coverage of data forced them to make decisions on how to proceed further with their analysis, and provided a good example of how scientific research is conducted. Our approach allowed students to actively engage in their learning and reach their goals, which were evidenced by their comments and their zeal to complete each part of the exercise; however, historic data collection is required to formalize these assertions. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/11-278.1]

Key words: soil classification, geochemistry, statistics, class exercise, effective instructional practices

INTRODUCTION

Promoting a genuine interest in science is important in properly introducing scientific topics and leading students along the path toward critical thinking. A well-rounded science background in the classroom also increases recognition of the importance and economic utility of scientific knowledge (Osborne et al., 2003; Swarat et al., 2012). Many science instructors go beyond these course objectives and strive to pique their students' interest in science enough to consider a career in science (Manduca, 2007; Perkins, 2007). Toward these ends, instructors must constantly reflect on and assess their teaching methods in order to know which effective instructional practices to incorporate in their teaching (Mogk, 2007; Perkins, 2007).

In science, inquiry-based solutions to authentic problems that are meaningful to students and that allow them to propose explanations based on the evidence of their own work hold great potential for engaging students (Manduca, 2007; Bell et al., 2010; Swarat et al., 2012). Effective instructional practices differ from conventional teaching in that they recognize that students have diverse learning styles, employ active-learning strategies, and promote inquiry and discovery (Manduca, 2007; Bell et al., 2010).

The soil exercise, to be completed in 6 h of class time, had the following objectives: (1) expose students to the methodology followed by scientists to conduct research and communicate results, (2) engage students in their learning by promoting meaningful discussions about the techniques utilized in the analysis of data and the reliability of results, (3) introduce students to statistical techniques that are commonly used in the analysis of geochemical data, and (4) reflect on the interconnection between clays and ionic substitution to soil make up and soil classification.

The Course

The college-level Principles of Geochemistry course, developed by the author in 2004, is structured in sessions of 50 min of lecture, followed by an equal time dedicated to case studies and in-class exercises. The class has been offered once a year, except for 2005 and 2009, and has had 6–18 students, with an average of 11 students, from which about 35% have been undergraduate and 65% graduate students (Table I). The course is an introduction to geochemistry, with a broad coverage of topics, from elements' abundance in the solar system, to weathering of rocks, to carbonate equilibrium, to geochemical modeling.

Students share the classroom, lectures, and exercises, but register either for GLG 460 or GLG 580, undergraduate and graduate levels, respectively. Graduate and undergraduate students have in common an interest in environmental sciences and have not taken a geochemistry course before. However, their background in chemistry varies. Graduate students come from three graduate programs: Geospatial Sciences-Environmental emphasis, Masters of Natural and Applied Sciences, or Environmental Chemistry. Undergraduate students are either geology-comprehensive or geology-non–comprehensive majors. With respect to expectations and grading, graduate students do additional work in the formal exercises and final projects.

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TABLE I: Student population for the geochemistry course according to status (U = undergraduate; G = graduate) and gender.

Demographic	Year						Avg (%)
	2004	2006	2007	2008	2010	2011	
U, female	4	4	1	0	1	1	1.8
U, male	3	2	1	1	2	3	2.0
G, female	3	4	2	5	6	2	3.7
G, male	3	1	2	4	9	2	3.5
Total	13	11	6	10	18	8	11
% Female	54	73	50	50	39	38	50
% Graduate	46	45	67	90	83	50	65

WHY SOILS?

Within the geochemistry course, clay minerals are taught after the chapters on ionic radii, bonds, and Goldschmidt's rules of ionic substitution. Clays superbly display ionic substitution, which partly explains the large variety of soils found in nature, in addition to being a most interesting mineral group (Hluchy, 1999; Dubey and Rule, 2007). However, in our class, clay minerals seemed to be unconnected to the other topics and were not needed or mentioned again in further sections.

The conventional teaching of clay minerals consisted of introducing the structure of clays, based on the tetrahedral and diocathedral layers, and how their arrangement determines structure, which is used for clay classification. The structure and composition of clays is quite complex, and the terminology can be overwhelming to students, especially considering that the topic had to be covered in a short time (two to three lectures). Although special properties and economic uses of each clay group were included, this information did little to add interest for the students, but rather only added to the information students were required to learn for the test. After a few attempts to better fit clay minerals into the rest of the course, with little success (e.g., class exercise matching clay with its properties, adding a special presentation on swelling clays), the idea of developing an exercise on soils came out after reading of an article (Anderson and Kravitz, 2010) that could be easily modified to fit our class in the form of a case-base activity, henceforth referred to as the "soil exercise."

Connecting the ionic substitution and clay mineral topics in a meaningful way and using them in a real-world application—soils—proved to be a good way to engage students and to involve them in the learning process. This soil exercise not only helped cover the material in a more significant and fun way, but also provided an opportunity to expose students to the methodology followed by scientists in conducting their research and sharing their results with the scientific community, and reinforced the application of statistics to interpret scientific data, a topic that ranks as very important background knowledge for senior/graduate students in the geosciences.

The American Geosciences Institute (http://www.agiweb.org/workforce/faqs/) stresses the importance of taking courses in statistics and mathematics in preparation for a successful career in geosciences. With the help of computers, geoscientists apply statistics and multivariate analysis to effectively test the hypothesis that the collected data was intended to resolve (Rogerson, 1990). In order to complement students' exposure to statistical applications in their discipline, instructors embed as many as possible case studies showing the application of statistics to solve geological problems.

The exercise aimed to involve students into their learning by fostering discussions among them on, e.g., which path to take to reach the most meaningful answer. The exercise (see the Supplemental Material; available online at http://dx.doi.org/10.5408/11–278.s1) included a component of both active learning and cooperative learning. Active learning consists of a classroom activity that engages students in the learning process, while cooperative learning is a type of student activity where students pursue common goals while being assessed individually (Prince, 2004; Bell et al., 2010).

THE EXERCISE

At first blush, it was evident that the article by Anderson and Kravitz (2010) contained all the elements needed for developing an exercise that would tie nicely in the geochemistry course and that would address the close relationship between clays and soils. The article is clearly written and provides a good background in soil analysis methods. For example, it lists normalized chemical composition as a key variable to study soils and adds that normalization can be performed in bases of Fe, Mn, or Al, which provides students with the required information and with choices as they agree on a path of analysis.

The goal of the class exercise was the same as that stated in Anderson and Kravitz (2010): ". . . to evaluate geochemical associations among different soil orders and as a screening tool for anthropogenic metal contamination." First, students were provided with basic information on soils, methodology, expected timeline, and an assignment sheet (included in the Supplemental Material; available at dx.doi.org/10.5408/11-278s1). The instructor conveyed this pertinent information and remained in the room throughout the time assigned for the lecture, even while students were working on their own tasks.

The 12 orders of soil taxonomy were briefly introduced with the U.S. Department of Agriculture (USDA) Web site (http://soils.usda.gov/technical/soil_orders/). This Web site presents each order in a simple and visual manner that was convenient for this exercise. Out of these 12 soil orders, only eight were represented in the dataset, while three contained the majority of the data. An introduction to clay minerals, their structure, and economic uses were previously covered in class as part of the course's curriculum. A copy of "Geochemical Association Plots as a Screening Tool for Environmental Soil Assessment" by Anderson and Kravitz (2010) was given to the students, and the methodology utilized in their investigation was thoroughly explained. The introduction of this article provided an opportunity for the instructor to explain how a scientific manuscript is prepared, its structure, what the process of peer-reviewing entails, and its role to the advancement of science. Students were reminded that they would apply the methodology described in this article to their own soil assignment.

Next, the soil data for the exercise were provided. The instructor had previously extracted the soil data from the set of more than 4,000 soil samples available from the USDA Natural Resources Conservation Service (NRCS)'s Cooperative Soil Survey Program (http://soils.usda.gov/survey/geochemistry/index.html). In order to make a data file more manageable for our soil exercise, the number of samples was reduced to 163 after extracting the samples collected from the top 30 cm of the soil profile and those located in the Great Plains area of the U.S. (longitudes −105° to −85° W). Similarly, and for simplification purposes, the number of variables was reduced from 20 to nine elements, from which eight were metals (Al, Fe, Ni, Zn, Cr, Cu, Mn, and Pb) and 1 was a metalloid (As). The extracted data file contained soil name, pedon code, soil-order taxon, sample depth, location (latitude and longitude), and concentrations of trace metals and major elements.

All together, the introduction (soil orders, methodology, soil data) took less than 2 h to complete, after which the group was asked to work in teams for specific tasks, and after their particular task was done, to take a look at the results, and together chart their next step. Students brought their personal laptop computers to class for the time needed to complete the exercise.

The first task consisted of organizing the data by soil order. The soil orders represented in the resulting data set were Alfisol (66 samples), Mollisol (61), Entisol (22), Aridisol (9) Inceptisol (4), Ultisol (5), Vertisol (4), and Spodosol (1). Students chose Al as the reference metal they all would normalize the metal concentrations with, and also which metal (Me) each had to plot. As the data set and procedure were somewhat different than those reported in Anderson and Kravitz (2010), the trends and conclusions were comparable to only a certain extent.

Pitfalls typical of real-world data soon became evident. Two elements, Mn and P, were reported twice in the original data, under each trace elements and major elements, and although the concentrations were similar in most cases, they were some discrepancies. Students had to look for an explanation for the differences (described in the "Analytical Procedures" in the NRCS sheet that accompanies the data); trace metals were extracted with an HNO_3–HCl mixture, while the mixture used to extract major elements was HF–HNO_3–HCl, in order to make a choice, as a group, of which to use. This was an eye opener to students who were used to the right–wrong type of choice, but in this case they had to make a decision as to which of the two values was the better and to what extent the difference among values was acceptable. This was also a good moment to stop and reflect on the goals of the exercise and the nature of the data. A second difficulty arose when they separated samples according to soil order and found out that only three accounted for most of the samples (Alfisols, 66; Mollisols, 51; Entisols, 22), while the other five contained only a few samples each. After reviewing the characteristics utilized in soil classification and considering possible options, students decided to eliminate soil orders containing less than five samples, and to add together Vertisols (4) and Ultisols (5) as one group for this exercise.

Students redefined the objectives of the study as following: (1) test if the soil orders could be differentiated based on their chemical composition, (2) apply the methodology that best separates background from anomalous (contaminated) concentrations, and (3) determine which elements show the strongest associations in each soil series.

Next, each student chose one particular element and one particular soil order to which to apply the analyses they had chosen, and worked on his/her own assigned metal and soil order, gathering information from their classmates as needed to see the results obtained for the other metals and other soil orders in order to widen the picture.

Soil Classification

The first sign of the educational value of the exercise was the reaction of the students to how soils are classified and what parameters are measured for their characterization. Pursuing a geochemical characterization of each soil order seemed a straightforward thing to do. Until the students had a closer look at the geochemical data, they realized that the task was a daunting one, and understood why soil scientists have to rely more on soil parameters such as texture, color, and organic matter content than on soil chemical composition.

Data Manipulation

A show of hands revealed that about two-thirds of the students felt uncomfortable with their statistics background, thus hinting that a basic approach to statistical methods would be needed. Even though the statistical software package SPSS (SPSS, Inc., Chicago, IL) was available, students were asked to use Excel (Microsoft, Redmond, WA) for the statistical analyses (semimanually) to gain an in-depth understanding of each step as well as to make result interpretation more meaningful.

Student Interaction

As both soil classification and statistics were new topics to most students, there was little difference in performance between them with regard to background knowledge in geochemistry, soils, or statistics. In contrast, there was a larger disparity in their command of Excel data management and graphing functions. The seating layout of the classroom consisted of large tables sitting four students each, providing plenty of space for a laptops and reference documents. A students seated next to a student experiencing difficulties with graphing were ready to give him/her a helping hand, most times without even leaving his/her seat. In the few occasions when more than one student needed help, the student who knew how to do that particular graphing task came forward to the room's computer, linked to the projector, and explained the steps to all. Because at the end of each section of the assignment students had to share and compare results, it was then in everyone's best interest to complete their tasks at about the same time.

Section 1 of the assignment was relatively simple, consisting on agreeing on a final data set and normalizing the concentrations. Sections 2–4 involved more work and cooperation; in these, students worked hard to complete as much as possible the tasks and to master the methods during the class time. Most students came to the next class with their final graphs neatly made, which showed that they had dedicated more time outside our class to the project and attested to their interest in the topics and their commitment on keeping up with the rest of their classmates. Once the analyses were completed, students were asked to turn in their final graphs, to reflect on their own work, and to write a few sentences on the validity of the results and their general impressions as well as to answer the questions:

(1) How are the chapters in ionic substitution and clay minerals related to this exercise?
(2) Which of the three statistical methods did you find more interesting and why?

RESULTS

In spite of the limited amount of time available to this exercise, all objectives were reached; students were introduced to a procedure used in real-life research for the 12 soil orders, and to three well-known statistical methods. The results are summarized below.

Students reached a consensus about using aluminum to normalize concentrations; The spodosols were excluded as the order contained only one sample, and Ultisol–Vertisol samples were merged into one group based on their chemical similarity (high correlation) and under the reasoning that because of the small number of samples on either order, having one group containing both was better than discarding these two groups.

As a first method to analyze the soil data, students constructed a log–log chart. A logarithmic transformation is necessary to approach normality, as soils do not follow a normal distribution (Chiprés et al., 2009). The procedure is simple: All values are converted to their logarithm, and then two variables (e.g., log Cu and log Al) are plotted on an x–y chart. Log–log charts show the degree of association between trace metals by the scattering of the points and a trend depending on the slope they show as a group (Anderson and Kravitz, 2010). The best fit was obtained by samples from the Ultisol–Vertisol group. For simplicity purposes, only a few of the many plots constructed by the students are shown here. Figure 1 shows the log–log plots obtained for Zn and Cu.

The conventional method for determining anomalous values (threshold between natural and contaminated values) based on standard deviation (±2 SD) does not apply to soils (Chiprés et al., 2009). Box plot (also known as a whisker diagram or a Tukey diagram) is a better choice, in that it takes into consideration factors such as the soil type and parent material (Chiprés et al., 2009). Box-plot diagrams are based on determinations of first and third quartiles, median, and upper and lower fence values. Figure 2 shows the box-plot results for normalized Cu, Ni, and Zn in Alfisols. Concentrations beyond the upper fence are concentrations corresponding to contaminated conditions, while background concentrations are those plotted within the box.

The third statistical method conducted on the data was cluster analysis. A cluster analysis is a method utilized to identify those variables (in this case, metals) that show a stronger association and shared common characteristics. Since students were performing all calculations with Excel, we used the simplest clustering method available, a technique called the weighted pair-group. As a first step, students used Excel to build a correlation table of the selected elements. The second step consisted of merging (clustering) those with the highest correlation. The process was repeated until there were only two variables left, a procedure students found repetitive and tedious.

Students were relieved to hear that the statistical packages can do all these steps at the click of a mouse. The resulting values were compiled and manually drawn as a dendrogram plot (Fig. 3).

The dendrogram showed which elements were more strongly associated. These results were discussed in class later within the context grouping elements according to the geochemical classification of elements by Goldschmidt (1937). Students were prompted to make further observations such as how these associations either prevailed or changed among soil orders.

Assessment

The students' answers to the questions asked at the end of the exercise were similar. A few examples are included below.

Question 1: How are the chapters in ionic substitution and clay minerals related to this exercise?

> *"Clay minerals are sources of high substitution that may explain the differences among soil orders."*
>
> *"This exercise focuses on the metals found in different soil types. This is related because substitutions occur in the clay leading it to become soil."*

Question 2: Which method did you find more interesting and why?

> *"The box-plot method was most interesting because it gives a clearer overall image."*
>
> *"Correlation is more interesting because it gives a clear trend in different types of soil data. A quick look at the correlation gives the nature of the soil one is dealing with."*

TABLE II: Average scores of Exam 2.

Parameter	Year					
	2004	2006	2007	2008	2010	2011
No. of students	13	11	6	10	18	8
Ave. score (%)	83.3	79.9	84.6	79.0	77.6	80.3

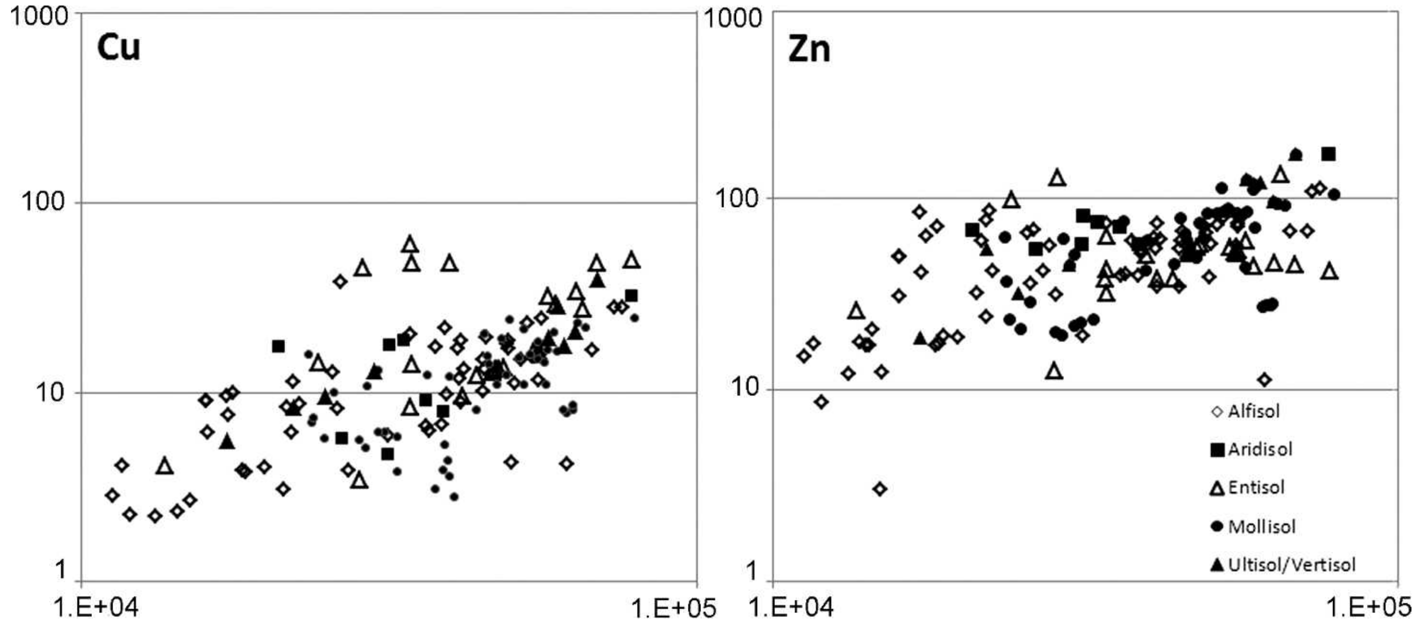

FIGURE 1: Example of student work. Log–log plots of Cu and Zn versus Al for five soil orders; concentrations in ppm.

> *"I liked doing the box plot, because it showed exactly what was ideal (median), what was a normal range, what was acceptable outside it, and what was outlier throughout the samples used. Also, it was less tedious than making the cluster plot."*

> *"Clay minerals are a big part of the mineral makeup of soils and can explain much about certain soil types, and ionic substitution can answer for many of the trace minerals in soils."*

From an historic perspective, the effectiveness of this exercise is much harder to document, as the soil exercise was first implemented in 2011. An attempt to document performance comparing the grades of Exam 2 from previous years to 2011 is shown in Table II. This attempt did not show conclusive results; the grade does not show a particular increase the year the exercise was implemented, partly because this exam covers topics other than clays and ionic substitution and partly because of the small number of students in the 2011 dataset. However, the informal evidence of commitment shown by students by their positive attitudes (dedicating additional time to make neat graphs though this was not required, the effort to keep up with other students, and/or to help classmates who were struggling with the graph function) and the amount of work accomplished during the short time indicate that this was an effective exercise.

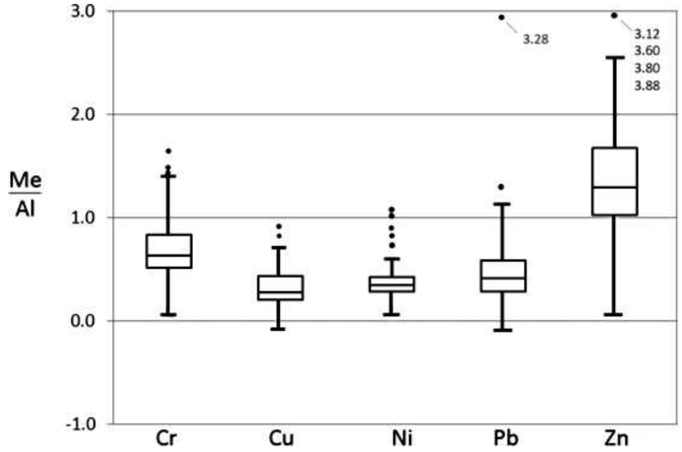

FIGURE 2: Example of student work. Box-plot diagram for normalized Me (metal) concentrations on Alfisols (soil order containing the most samples). The center horizontal line represents the median encompassed by the 50th percentile. The whiskers (lines) are the threshold values while the dots represent anomalous concentrations.

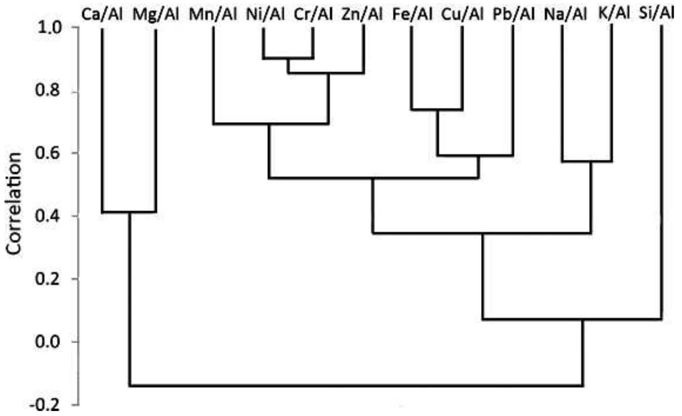

FIGURE 3: Example of student work. Cluster diagram obtained for normalized element concentrations in Alfisols. The dendrogram was constructed by the weighted pair-group method. Highest similarities are linked first; in this case Ni–Cr and Zn.

Based on how well received this exercise was the first time it was conducted, it will likely be included as part of the course in forthcoming years, after which more documentation will be available to formalize the evaluation of it as an effective learning tool. In addition, retaining the three questions mentioned above as an assessment tool and utilizing the answer to assignment questions as a posttest, a pretest will be added to document learning. In addition, answers to specific questions of clays and ionic substitution in Exam 2 will be monitored in order to test retention of knowledge several weeks after the material was covered.

CONCLUSION

Reflecting on one's teaching methods likely leads to more effective teaching, which is a highly recommended practice in sciences. Through an active learning exercise, students in an introductory geochemistry class were engaged in applying their previous knowledge of ionic substitution and clay minerals while working on a real-world application, the formation of soils, where the former two are key contributors. Students read and became familiar with a scientific article, and in this way they were exposed to how scientists share their results and the way these communications are utilized and, in the process, reviewed by fellow researchers.

From the content point of view, soil classification and two to three statistical tests commonly used in geology were a valuable addition to their background knowledge. The exercise filled a gap in what was needed to connect the study of clays with other topics covered in class and was well received by students, evident from their readiness to complete the tasks and by their positive comments. A more formalized evaluation of the exercise will be conducted once the exercise is done again and the proper documentation is collected.

An additional benefit of the approach followed by this exercise is that it can easily be applied to cover to any topic in geosciences. The time and effort spent by the instructor looking for a suitable article to cover the topic he/she wants to focus on will likely pay off with students becoming more engaged, which will lead to an enhancement of students' learning outcomes.

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