International Journal of Science Education, 2015
Vol. 37, No. 9, 1436–1453, http://dx.doi.org/10.1080/09500693.2015.1041434

'Teaching What I Learned': Exploring students' Earth and Space Science learning experiences in secondary school with a particular focus on their comprehension of the concept of 'geologic time'

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According to the national survey of science education, science educators in the USA currently face many challenges such as lack of qualified secondary Earth and Space Science (ESS) teachers. Less qualified teachers may have difficulty teaching ESS because of a lack of conceptual understanding, which leads to diminished confidence in content knowledge. More importantly, teachers' limited conceptual understanding of the core ideas automatically leads to a lack of pedagogical content knowledge. This mixed methods study aims to explore the ways in which current secondary schooling, especially the small numbers of highly qualified ESS teachers in the USA, might influence students' learning of the discipline. To gain a better understanding of the current conditions of ESS education in secondary schools, in the first phase, we qualitatively examined a sample middle and high school ESS textbook to explore how the big ideas of ESS, particularly geological time, are represented. In the second phase, we quantitatively analyzed the participating college students' conceptual understanding of geological time by comparing those who had said they had had secondary school ESS learning experience with those who did not. Additionally, college students' perceptions on learning and teaching ESS are discussed. Findings from both the qualitative and quantitative phases indicate participating students' ESS learning experience in their secondary schools seemed to have limited or little influence on their conceptual understandings of the discipline. We believe that these results reflect the current ESS education status, connected with the declining numbers of highly qualified ESS teachers in secondary schools.

Key words: *Earth and Space Science; Geologic Time; PCK; Mixed methods*

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Introduction

Science educators currently face many challenges while teaching in secondary schools. Among these is a lack of qualified discipline-specific teachers. For instance, a biology teacher in an urban high school located in the Midwest USA shared her concerns that her science department did not have anyone who could teach Earth and Space Science (ESS). As a science department head, she was challenged to satisfy requirements suggested by the state educational association. Our brief conversation raised a series of questions such as 'Do other schools or other states have the same issues?', 'Who teaches ESS courses in secondary schools?', and 'How do students learn ESS in their secondary schools?'

In their 2010 study, Lewis and Baker offered a glimpse into current ESS education. In their view, ESS education in the USA now faces a lack of qualified teachers and low enrollment at both secondary and post-secondary levels. Additionally, ESS is not central to the curriculum in middle and high school science classrooms; even though many reform documents have continuously emphasized ESS as much as other science disciplines (e.g. American Association for the Advancement of Science, 1993; National Research Council [NRC], 1996, 2012). For example, virtually all high schools offer at least one biology course, nearly all offer chemistry, and somewhat fewer offer physics. In contrast, ESS courses are only offered in about half of high schools (Weiss, 2002). As a result, ESS educators and Earth and Space scientists are now facing a lack of students with an interest in learning and teaching ESS-related courses and pursuing ESS as a career path (Lewis & Baker, 2010).

Low enrollment at both secondary and post-secondary levels may also result in smaller numbers of highly qualified ESS teachers in secondary schools. Based on the National Assessment of Educational Progress (NAEP, 2000), only 19% of all 8th grade ESS teachers have undergraduate majors in geosciences; 39% have other science majors, 21% are elementary certified, and 21% are not certified at all. About 15% of all high school science teachers are assigned to teach one or more sections of ESS, and of these teachers, only 72% are certified to teach ESS and have a major or a minor concentration in the field (Blank & Langesen, 2005; Weiss, 2002). This implies that ESS classes are more likely to be taught by non-specialist teachers than is the case in other science disciplines. Unfortunately, the Horizon Research group's most recent report (Banilower et al., 2013) showed that this trend had continued in the decade since the 2000 national survey of science and mathematics education (Weiss, 2002). The results indicate that only a relatively small number of secondary science teachers had taken ESS courses in college. Only 25% (middle school) and 38% (high school) of secondary ESS teachers are well qualified in terms of their disciplinary backgrounds.

The declining numbers of highly qualified ESS teachers in secondary schools may have had a crucial impact on lowering students' interest in learning ESS. Those ESS teachers who are not qualified in this subject may have difficulty teaching the discipline because of a lack of conceptual understanding, which could lead to less confidence in content or subject-specific knowledge. Many studies have shown that a low confidence in content knowledge impacts teaching practices (Dahl, Anderson, & Libarkin, 2005; Trend, 2001). Of course, conceptual understanding of science cannot be seen as the only criteria for becoming a good teacher, but it does play a crucial role in teaching as well as in student learning (Hashweh, 1987). Although multiple variables exist for assessing teacher 'quality', previous studies have indicated that the percentage of teachers with full certification and a major in the field is a powerful predictor of student achievement (e.g. Darling-Hammond, 2000).

More importantly, teachers' limited conceptual understanding automatically leads to a lack of pedagogical content knowledge (PCK), which is a necessary body of knowledge for science teaching (Park, Jang, Chen, & Jung, 2011). According to Shulman, PCK is described as a blend between content and pedagogy demonstrated by an understanding of how to translate content knowledge into 'forms that are pedagogically powerful and yet adaptive to the variation in ability and background presented by the students' (Shulman, 1987, p. 15). Krauss et al. (2008) reported that higher expertise often involves stronger integration of different knowledge categories, and thus that content knowledge seems to form a common body of expertise in teachers, with high levels of content knowledge and PCK alike. Furthermore, in Park and Oliver's (2008) model of PCK for teaching science, content knowledge is embedded within all five components of effective science teaching: (1) orientation to teaching science, (2) knowledge of students' understanding in science, (3) knowledge of science curriculum, (4) knowledge of assessment of science learning, and (5) knowledge of instructional strategies for teaching science.

With this in mind, this study aims to explore the ways in which current secondary schooling, especially the small numbers of highly qualified ESS teachers, might influence students' learning of the discipline. There is little research on what learning experiences students actually encounter while studying ESS in secondary school and in what ways these experiences influence their understanding of the subject. To gain an understanding of the current conditions of ESS education in secondary schools, this study qualitatively examined how the big ideas of ESS are represented in a sample middle and high school ESS textbook; one example of teaching materials ESS teachers might use. Based upon the findings of this qualitative phase, this study examined the college students' perception of teaching and learning ESS and their conceptual understanding of ESS, particularly a topic of *geologic time*, by comparing those who said they had received secondary school ESS learning experience with those who said they had not.

Textbooks for Teaching and Learning Science

Knowledge of the science curriculum is one of components of effective science teaching (Park & Oliver, 2008). According to national surveys in the USA (i.e. Banilower et al., 2013; NAEP, 2000; Weiss, 2002), only small numbers of secondary ESS teachers are highly qualified. Less qualified teachers may have difficulty teaching ESS because of a lack of conceptual understanding, which leads to diminished confidence in content knowledge. Therefore, teachers are more likely to rely on teaching materials such as textbooks. For example, in a case study of a middle school science teacher, Lee (1995) reported a strong relationship between the teacher's limited conceptual understanding of the topic and a heavy reliance on the textbook. Moreover, under the current accountability system, many secondary school teachers are forced to improve students' performance on standardized tests, and as a result most science teachers still rely on textbooks as the primary source of the classroom curriculum (Stern & Roseman, 2004; King, 2010). Of course, due to a variety of teaching materials, it might be problematic to state that less qualified ESS teachers are more likely to rely particularly on textbooks.

Yet, textbooks reflect the value of standards and curriculum in the current education system. Textbook developers consistently revised their versions responding to the needs and changes of contemporary science education. In fact, in Weiss's (2002) report, 86% of middle school science teachers and 94% of high school science teachers responded that they used commercially produced textbooks in their classrooms. While it is difficult to say whether ESS teachers rely only on textbooks for their instruction, analyzing textbooks will provide how the major scientific concepts suggested by national and local standards are represented for secondary science lessons. In this regard, the first goal of this study was to qualitatively examine examples of middle and high school Earth science textbooks to investigate how the textbooks represent the disciplinary core ideas of ESS, focusing on three dimensions that contain the type of knowledge and cognitive processes, and the rhetorical mode.

Geologic Time as One of Disciplinary Core Ideas in ESS

Among multiple core ideas in ESS, this study focused on the topic of geologic time. Dodick and Orion (2003a) argued that a critical element of ESS, especially of geology, is reconstructing geological structures and systems that have developed over time. ESS learners, therefore, are required to comprehend geologic time to deepen their understanding of the structure and systems of the Earth. Despite this requirement, however, Dodick and Orion (2003b) argued that science education researchers have paid little attention to the concept of geologic time. This lack of attention might have influenced the insufficient efforts on curriculum design and/or teacher education programs involving this unit. For example, previous studies reported that many in-service teachers felt a low level of confidence in their ability to teach the concept of geologic time since those teachers seldom possess adequate content knowledge needed to teach Earth history and geologic time (Dahl et al., 2005; Trend, 2001). Therefore, students' deep understanding of geologic time can be seen as one of the critical goals in ESS education.

Additionally, the topic of geologic time might reflect on one of the unique characteristics of ESS, and of Earth science in particular. Kleinhans, Buskes, and Regt (2010) stated that 'the theories of Earth science are typically hypotheses about unobservable (past) events or generalized—but not universally valid—descriptions of contingent processes' (p. 1). According to Trend's (2001) definition, ESS, especially geology, is the science with a clear focus on deep time and the procedures of *retrodiction*—making a prediction about the past, while most other sciences deal with times of shorter duration (p. 541). Therefore, the topic of geologic time provides students with opportunities to learn the unique characteristics of ESS by exploring the history of the Earth and the planet's process of changes, which is one of disciplinary core ideas in ESS suggested by the Next Generation Science Standards (NGSS): (a) Earth's place in the universe, (b) Earth's systems, and (c) Earth and human activity. The NGSS is a new version of the national science education standards in the USA that highlight three dimensions, which include providing a greater emphasis on depth over breadth of science *content*, asking students to apply their learning through the *practices* of scientific inquiry and engineering design, and emphasizing *crosscutting concepts* which bridge disciplinary boundaries and unit core ideas throughout the fields of science and engineering (NRC, 2012). In other words, it could be argued that students who had a meaningful ESS learning experience in secondary schools would have a more sophisticated understanding of geologic time compared with those who did not.

Building on these considerations, this mixed methods study aims to explore the ways in which current secondary schooling, especially the small numbers of highly qualified ESS teachers, might influence students' learning of the discipline. To gain a better understanding of the current conditions of ESS education in secondary schools, in the first phase, we qualitatively examined a sample middle and high school ESS textbook to explore how the big ideas of ESS, particularly geological time, are represented. In the second phase, we quantitatively analyzed the college students' conceptual understanding of geological time by comparing those who said they had received secondary school ESS learning experience with those who did not. Additionally, college students' perceptions on learning and teaching ESS are discussed. Research questions that guided this study included the following:

1. In what ways are the big ideas of ESS, particularly geologic time, represented in two sample secondary school ESS textbooks, focusing on types of knowledge, cognitive processes, and rhetoric modes?
2. Do ESS learning experiences in secondary school help students' understanding of geologic time?
3. What are college students' perceptions of ESS learning and teaching?

Methods

Research Design

This mixed method study largely adopted the *multiphase* research design (Creswell & Clark, 2010). The major purpose of using the multiphase research design, particularly two-phase design, was that the findings of the first method could help develop or inform the second method (Greene, Caracelli, & Graham, 1989). In the first phase of this study, researchers began collection and analysis of qualitative data. Building on the qualitative or exploratory findings, we then conducted a second phase. This

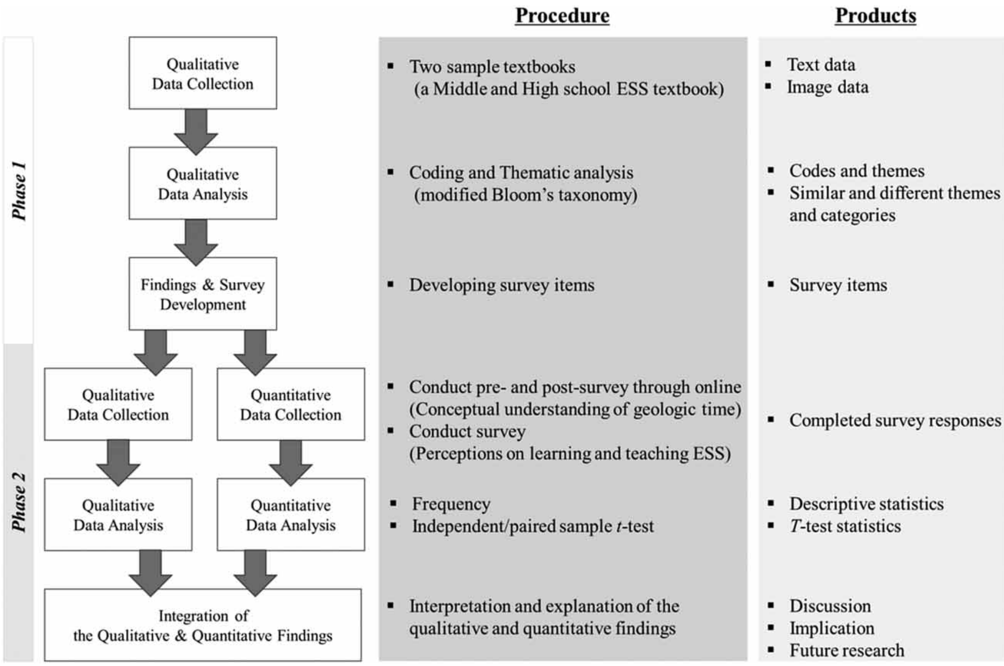

Figure 1. The multiphase mixed methods research design for this study

design is particularly useful when the researcher needed to combine both sequential and concurrent strands over a period of time (Creswell, 1999; Creswell, Fetters, & Ivankova, 2004). Additionally, this design incorporates the flexibilities needed to utilize the mixed methods design elements required to address a set of interconnected research questions. Figure 1 illustrates the research design for this study.

Data Collection and Analysis

Phase 1: Qualitative study of secondary school textbooks. In the first, qualitative phase, we employed a directed content analysis to explore in what ways the big ideas of geologic time are communicated in two sample secondary school ESS textbooks.

Data collection. One sample middle school earth science textbook and one sample high school earth science textbook designed by the same publisher were collected. During the selection process, we considered diverse middle and high school textbooks by different publishers because there is no nationally accepted earth science curriculum in the USA. Therefore, we selected textbooks based on three criteria: (1) most commonly used, (2) certified by qualified organizations, and (3) accessible to researchers. As a result, we selected sample middle school and high school ESS textbooks by the same publisher, which were some of the most commonly used in middle and high school ESS classrooms in the USA as reported by the national survey of science and mathematics education (see Banilower et al, 2013; Weiss, 2002), and were certified by the National Science Foundation. Three units in each textbook related to geologic time were analyzed.

Data analysis. A directed content analysis was employed for the first phase. A directed content analysis is a method to use existing theory or prior research for identifying key concepts or variables as initial coding categories (Potter & Levine-Donnersten, 1999). In the textbook analysis, we largely employed a framework suggested by Anderson and Krathwohl (2001), which revised Bloom's (1956) taxonomy of educational objectives. The authors classify knowledge by dividing it into two dimensions: 'knowledge' as what learners know and 'cognitive process' as how they think about what they know. Under this framework, the knowledge dimension includes four general types of knowledge: (a) *Factual*, (b) *Conceptual*, (c) *Procedural*, and (d) *Metacognitive*. The cognitive process dimension is divided into six categories: (a) *Remembering*, (b) *Understanding*, (c) *Applying*, (d) *Analyzing*, (e) *Evaluating*, and (f) *Creating*. In addition, we explored how written texts represented scientific ideas to readers, focusing on four classifications of rhetorical mode: (a) *Exposition*, (b) *Description*, (c) *Narration*, and (d) *Argumentation*. These three dimensions were employed in the data analysis for this study in order to focus on how the big ideas of geologic time were represented in two sample textbooks.

The sample textbooks that were analyzed contained multiple units, each unit consisting of multiple sections such as objects, general contents, activity, and evaluation; we focused only on the general contents. To identify a category of knowledge and cognitive process, we separated written texts into paragraphs and used these as the basic unit for examining the two dimensions. Some paragraphs emphasized two or more types of knowledge and cognitive processes. In those cases, we used double coding. Throughout the data analysis we developed and set rules for the identifying system through an iterative process that occurred over several months of regular weekly meetings. Both authors collaborated in the development of the classification and had primary responsibility for resolving problems in classifying particular paragraphs. We continuously discussed the consistency of the data analysis so that final codes from each author, calculated by Miles and Huberman's (1994) formula, were 90%, and the value of Cohen's kappa was 0.89. Disagreements were resolved through discussion.

Phase 2: Survey of college students taking an introductory ESS course. In the second phase, we analyzed the college students' conceptual understanding of geological time by comparing those who said they had had secondary school ESS learning experience with those who did not. Additionally, in the pre-survey, we asked students' thoughts about: (a) their difficulties in learning ESS, (b) their personal level of ESS understanding, (c) the difference between learning ESS and learning physics, (d) reasons for experiencing difficulty learning ESS, and (e) ways to tutor ESS to high school students, as a means of further exploring how their ESS learning experiences influenced their attitudes toward the discipline.

Context and participants. In the second phase, we collected college students' responses to the survey. Three hundred undergraduate students who took the course 'Introduction to Earth Science' in a state university located in the Midwest USA were the focus of the study. The course was taught by one of the authors and dealt with general concepts of ESS for general undergraduates. The instructor blended the nine big ideas proposed by *Earth Science Literacy Initiatives* in his lessons, and lessons covered all concepts of geologic time used in the survey, focusing on students' conceptual understanding. Participating college students' majors varied from science-relevant majors such as geosciences and engineering to non-science-relevant majors such as history, business, and English. Approximately 81% of students responded that they took this course as a requirement for a major. Students also took the course because of their interest in ESS (17%). About 32% of students who responded that they took the course to fulfill a requirement for their majors also responded that they had an interest in learning about ESS.

The college students voluntarily participated in the online-based survey, and there was no compensation or credit for participation. We recruited students through a brief presentation before the first lesson and sent out an email that explained the purpose of the study and included the website address. Students automatically participated in the survey by clicking on the hyperlinked address. Pre- and post-surveys were conducted. The pre-survey was conducted at the beginning of the semester and the post-survey at the end of the semester. The items on the post-survey, which were designed to measure students' conceptual understanding of geologic time, were identical to those on the pre-survey, but the five questions measuring students' perceptions of ESS were only used in the pre-survey. Students had learned the entire core ideas related to this study before the post-survey. In total, 106 students completed the pre-survey and 51 completed the post-survey. Participants in the survey were separated into two groups depending on their secondary school learning experience of taking an ESS-related course. We coded these two groups as: (a) *Group 1*, a group who said they had had ESS learning experience in secondary school, and (b) *Group 2*, a group who said they had not had ESS learning experience. The Group 1 students had taken at least one course such as Earth Science, Environmental Science, Geology or Geoscience, or other ESS-related courses during middle or high school. In our survey, the breakdown was Earth science (34.9%), Environmental science (23.6%), Geology or Geoscience (13.2%), and Others (16.2%).

Quantitative data collection. To create survey items, we largely used preexisting items adopted from the Geoscience Concept Inventory, which is an assessment tool grounded in alternative conceptions research, currently used by multiple universities for assessment purposes (e.g. Michigan State University, San Diego State University). We purposefully selected items that focused on students' conceptual understanding of geologic time. We initially selected 40 items, sorted them based on difficulty, and finally created a survey consisting of 14 items. These 14 multiple-choice questions focused on students' conceptual understanding of geologic time. Three graduate teaching assistants who majored in Geosciences reviewed the items to examine their difficulty level, and all agreed that the difficulty level of 14 items measuring participants' conceptual understanding of geologic time was appropriate for both science major and non-science major college students who were taking an introductory course offered by the Geosciences department.

Qualitative data collection. In addition to the survey items that examined students' conceptual understanding of ESS, we also asked about their perceptions of ESS learning and teaching. Five questions were asked. To measure students' views regarding the difficulty of learning ESS and the level of their own understanding of the subject, a four-point Likert-type scale was used. The responses to the difficulty statement were scored as 'Extremely difficult = 1', 'Very difficult = 2', 'Somewhat difficult = 3', and 'Not very difficult = 4'. The responses to the level of understanding statement were scored as 'Very weak = 1', 'Somewhat weak = 2', 'Somewhat strong = 3', and 'Very Strong = 4'. The coefficient of internal consistency (Cronbach's alpha) of the scale was $\alpha = 0.65$. The other three questions were short essay questions that explored students' views about the differences between learning ESS compared with Physics, their reasons for experiencing difficulty learning ESS, and about effective teaching methods.

Quantitative data analysis. The data analyzed comprised the test scores examining students' conceptual understanding of ESS. The following analyses were undertaken to examine the research hypotheses. The independent samples t test was performed to compare the means of the pretest scores of the two groups, the posttest scores of the two groups, the pretest and posttest scores of Group 1, and the pretest and posttest scores of Group 2. All analyses were tested for significance at the 0.05 level.

Qualitative data analysis. Five additional questions on the pre-survey asked for participants' perceptions on ESS learning and teaching. Responses of the 106 students to these five multiple-choice and short essay questions on perceptions were qualitatively analyzed and descriptively reported. An analysis of the content was used to identify themes in the responses, to develop categories of responses based on common themes, and to tabulate the number and percentage of frequent responses for each category.

Findings

Phase 1

The research question for this phase was: *In what ways are the big ideas of ESS, particularly geologic time, represented in two sample secondary school ESS textbooks, focusing on types of knowledge, cognitive processes, and rhetoric modes?* In this section, we describe the identifying patterns or themes within the data that emerged from our analysis of the knowledge, cognitive processes, and rhetorical modes represented by the texts.

Analysis of the types of knowledge employing the revised Bloom's taxonomy showed that *Conceptual Knowledge* was predominantly represented in secondary school textbooks (Middle school earth science textbook (MS), 87.0%; High school earth science textbook (HS), 89.1%). This was followed by *Factual Knowledge* (MS, 13.0%; HS, 10.9%). The other two types of knowledge did not appear in our analysis. In terms of cognitive process, data analysis indicated that textbooks required readers' *Understanding* (MS, 61.4%; HS, 65.9%) most often, followed by *Remembering* (MS, 17.7%; HS, 19.0%), *Analyzing* (MS, 14.2%; HS, 12.8%), and *Applying* (MS, 6.3%; HS, 2.3%). Few parts required readers to engage in the cognitive processes of *Evaluating* and *Creating*.

We also examined the interrelation between types of knowledge and cognitive processes (Table 1). Data analysis revealed that both textbooks required readers' *Understanding* + *Conceptual Knowledge* (MS, 57.5%; HS, 65.9%) most often. *Analyzing* + *Conceptual Knowledge* (MS, 14.2%; HS, 12.8%) was the next most frequent combination. In the sample middle school textbook, *Remembering* + *Conceptual Knowledge* (9.4%), *Remembering* + *Factual Knowledge* (8.3%), *Applying* + *Conceptual Knowledge* (5.5%), *Applying* + *Factual Knowledge* (0.8%), and *Creating* + *Conceptual Knowledge* (0.4%) followed. In the sample high school textbook, *Remembering* + *Factual Knowledge* (10.9%), *Remembering* + *Conceptual Knowledge* (8.1%), and *Applying* + *Conceptual Knowledge* (2.3%) followed. These findings illustrate that only a few types of intersections appeared in both textbooks.

Table 1. Frequency of focused types of knowledge and cognitive process

			Knowledge				
			Factual knowledge	Conceptual knowledge	Procedural knowledge	Metacognitive knowledge	Total
Cognitive process	Middle school	Remember	21	24	0	0	45
		Understand	10	146	0	0	156
		Apply	2	14	0	0	16
		Analyze	0	36	0	0	36
		Evaluate	0	0	0	0	0
		Create	0	1	0	0	1
		Total	33	221	0	0	254
	High school	Remember	28	21	0	0	49
		Understand	0	170	0	0	170
		Apply	0	6	0	0	6
		Analyze	0	33	0	0	33
		Evaluate	0	0	0	0	0
		Create	0	0	0	0	0
		Total	28	230	0	0	258

In terms of rhetorical strategies for representing scientific knowledge, the textbooks used *Exposition* as the major rhetorical device (MS, 68%; HS, 75.8%). *Description* (MS, 22.8%; HS, 20.9%) and *Narration* (MS, 9.2%; HS, 3.3%) followed. The middle and high school textbooks did not include *Argumentation* as a rhetorical mode.

Bridge to the Next Phase

The textbook analysis suggested that: (1) *Conceptual Knowledge* was predominantly represented in secondary school textbooks (MS, 87.0%; HS, 89.1%); (2) textbooks most often required readers' *Understanding* (MS, 61.4%; HS, 65.9%); and (3) textbooks used *Exposition* as the major rhetorical device for representing scientific knowledge (MS, 68%; HS, 75.8%). In other words, the two sample secondary school ESS textbooks focused on providing the core ideas of ESS through expository texts (*finding 3*) to represent conceptual knowledge (*finding 1*) and required students to understand (*finding 2*) the knowledge. With this in mind, we concluded that the sample textbooks used for this study highlighted students' conceptual understandings of geologic time that emerged in expository texts, and proposed a hypothesis that college students who had ESS learning experience in secondary school might have a better understanding of ESS concepts than those who had not. To further explore this hypothesis, we designed the next phase of this study, to address the second and third research questions: *Do ESS learning experiences in secondary school help students' understanding of geologic time? What are college students' perceptions of ESS learning and teaching?*

Phase 2

Students' conceptual understanding of geologic time. In the second phase, we coded students into two groups: (a) Group 1, a group with ESS learning experience in secondary school and (b) Group 2, a group without ESS learning experience. The two groups' pre- and post-survey results were examined. The pre-survey showed no significant difference between the groups, indicating no difference in students' conceptual understanding of ESS focusing on geologic time. Similarly, the post-survey indicated no significant difference between the groups. Table 2 contains a summary of the independent *t*-test comparing the mean scores of students' performances in both Group 1 and Group 2 regarding the pretest and posttest scores. The results indicate that students' secondary school ESS experiences appear to have limited or little

Table 2. Independent *t*-test results of the data gained from the test focusing on geologic time

Tests	Groups	*N*	Mean	SD	*t*	*p*
Pretest	Group 1	74	6.66	2.96	0.06	0.95
	Group 2	32	6.63	2.40		
Posttest	Group 1	33	9.27	2.43	0.52	0.60
	Group 2	17	8.88	2.64		

influence on their conceptual understandings of the discipline at the college level, at least in relation to 'geologic time'.

A paired-samples *t*-test was conducted to compare students' test scores prior to and after instruction conditions. Although this study did not aim to measure the effectiveness of the instruction offered to participants, this comparison might help to further explore whether college students' ESS learning experience positively influenced their conceptual understanding. We hypothesized that the instruction possibly helped them to remember, recall, and reconstruct their background knowledge of the discipline, which might not have been activated in the pretest. The use of a paired sample *t*-test on the gathered data reveals that both Group 1 ($t(32) = -3.289$, $p < 0.05$) and Group 2 ($t(16) = -3{,}561$, $p < 0.05$) showed statistical improvement in conceptual understanding of geologic time (Table 3). To measure the size of the difference between pre and posttest scores, we compared effect sizes of the groups by employing Cohen's *d*. The effect size of Group 1 was 0.96 and that of Group 2 was 0.91, indicating that college students in both groups similarly improved their conceptual understanding regardless of their previous ESS learning experience in secondary school.

Students' perceptions of ESS. In addition to assessing their conceptual understanding of geologic time, we added five questions to the pre-survey asking about college students' perceptions on ESS learning and teaching. This section descriptively reports the results of those questions.

Q 1: Level of personal understanding of ESS. First, college students' views of the level of their personal understanding of ESS indicated that both groups most often identified themselves as 'somewhat weak' (Group 1, 48.6%; Group 2, 46.9%). However, the Group 1 students—those with secondary school ESS learning experience—responded that they had relatively stronger background knowledge of ESS than those students in Group 2. Group 1 students identified themselves more often as 'somewhat strong' (45.9%) than Group 2 students (34.4%), and identified themselves less often as 'very weak' (5.4%) than Group 2 students (18.8%).

Table 3. Paired *t*-test results of the data gained from the test focusing on geologic time

Groups	Tests	*N*	Mean	SD	*t*	*p*
Group 1	Pretest	74	6.66	2.96	−3.29*	0.002
	Posttest	33	9.27	2.43		
Group 2	Pretest	32	6.63	2.41	−3.56	0.003
	Posttest	17	8.88	2.64		

*Significant at $p < 0.005$ (Sig. 2-tailed).

Q 2: Level of difficulty in learning ESS. Second, college students' view of the difficulty of learning ESS was examined. Overall, most students in both groups thought learning ESS was somewhat difficult (Group 1, 58.1%; Group 2, 56.3%). Only a small number of students responded that learning ESS was very or extremely difficult. However, the students in Group 1 were less likely to perceive ESS as challenging than those in Group 2. Group 1 (33.8%) more often perceived ESS as 'not very difficult' than Group 2 (28.1%) and less often answered that ESS was 'very difficult' (5.4%) than Group 2 (12.5%).

Q 3: Challenges in learning ESS. In this short essay question, students' responses ranged widely and were therefore categorized based on their contents. Many participants in both groups responded that 'abstract and difficult concepts' were the biggest challenge contributing to their difficulty in learning ESS (Group 1, 34%; Group 2, 45%). Interestingly, 34% of Group 1 students responded that they had difficulty when memorizing or remembering terminology, while only 18% of Group 2 students did. Additionally, participants in Group 1 also responded that they had 'no or little interest in learning ESS' (7%), 'insufficient time to study, lecturing style, or negative experience of secondary ESS teachers' (5%), and 'difficulty reading textbooks' (4%), while there were no such responses from the students in Group 2. A small number of participants in both groups indicated that 'difficulty applying concepts, laws, or theories to other disciplines or daily life' (9%) contributed to their difficulty with the subject matter.

Q 4: Difference from other science disciplines. In this question, we categorized students' responses into five categories based on their contents. Approximately half of the students in both groups responded that there was no difference between learning the two subjects. However, students in Group 1 were more likely to view learning ESS as different from learning physics (Group 1, 25.7%; Group 2, 18.8%). Only those students who believed that learning ESS was different than learning physics explained their reasons, except for some students who responded, 'I don't know'. Students' written responses varied, but four patterns emerged.

The first, a predominant pattern, appeared in 11 responses out of 106 responses. Students seemed to believe that using mathematical concepts, formulas, or equations in physics was the biggest difference from learning ESS. For example, they responded, 'No. Physics deals with more mathematical concepts', or 'No, I presume there are fewer equations in earth science than in physics', or 'No, learning earth science requires more memorization and doesn't require a lot of equations'. Five student responses illustrated the second pattern that learning ESS was closer to learning chemistry or biology than to learning physics. As a third pattern, three students responded that physics could be used for understanding the natural phenomena that ESS dealt with. For example, these students responded, 'No, though physics does play a part in geology' or 'Not really, but in class, the professor said that to be a geology major, you need to know chemistry and physics'. As a final pattern, two students wrote, 'No. Earth Science seems to be less abstract and more colorful than physics'. The other four students who agreed that there was a difference between ESS and physics did not add their reasons.

Q 5: Effective ways to teach ESS. Although students' responses ranged widely, many students who had secondary school ESS learning experience, interestingly, responded to this question that they would teach the high school student what they had learned. For example, some wrote contents or concepts they had learned regarding ESS such as 'plate tectonics', 'volcanoes', 'types of rocks', or 'earthquakes, tornados, and other natural disasters'. Others mentioned strategies they experienced while learning Earth Science during secondary school, such as, 'reading the textbook', 'reviewing chapters', or 'just showing them different ways to study and go over notes and questions at the end of each chapter'. A few students emphasized details, examples, and using alternative representations, such as 'explain everything with a lot of detail and good examples', 'try and find relatable examples', or 'use visual elements like movies and diagrams'. It might be difficult to categorize the wide range of responses, but most seemed to reflect students' general learning science experiences regardless of their ESS experience in secondary school.

Discussion

This study began with an overview of the challenges in current ESS education. Despite educators' efforts over the last decade, the national survey of science education (Banilower et al., 2013; Weiss, 2002) reports that ESS is currently facing a lack of students with an interest in learning and teaching ESS-related courses and pursuing ESS as a future career. This unfortunate reality led us to explore students' ESS learning experiences in secondary school by employing the multiphase mixed method research design.

In the first phase, findings suggested that the sample textbooks used for this study highlighted students' conceptual understandings of geologic time (findings 1 and 2) that emerged in expository texts (finding 3), and proposed a hypothesis that college students who had ESS learning experience in secondary school (Group 1) might have a better understanding of ESS concepts than those who had not. Yet, in the second phase, students in Group 1 appear to have limited or little influence on their conceptual understandings of the discipline at the college level. Additionally, college students in both groups perceived that they had somewhat weak understanding of ESS, and also felt somewhat difficult to understand scientific concepts in ESS. College students in Group 1 viewed memorizing or remembering abstract and difficult concepts as the biggest challenges in learning ESS in secondary schools. To a question asking the most effective methods for teaching high school students, many students in Group 1 responded that they would teach ESS in the way that they had learned it. We believe that these results reflect the current ESS education status, connected with the declining numbers of highly qualified ESS teachers in secondary schools, and also offered three critical points ESS educators should pay attention to.

First, less qualified teachers may have difficulty teaching ESS because of a lack of conceptual understanding, which leads to diminished confidence in content knowledge (Lee, 1995). More importantly, lack of content knowledge automatically leads to lack of PCK, which is a necessary body of knowledge for science teaching (Park et al., 2011). The NGSS highlight that students must be engaged at the nexus of the three dimensions: (a) disciplinary core ideas, (b) science and engineering practices, and (c) crosscutting concepts, not as separate entities. From perspectives on PCK and NGSS, it could be argued that less qualified teachers may have other problems beyond a lack of content knowledge or confidence. That is, poorly qualified teachers' lack of PCK may result in providing limited or fewer opportunities for students not only to understand the core ideas, but also to engage in the scientific and engineering practices, so that students may not be able to have broader understanding of science and to apply their developing scientific knowledge to the solution of practical problems.

Second, it is important to note that although multiple variables exist for assessing teacher quality, Darling-Hammond (2000) argued that the percentage of teachers with full certification and a major in the field is a powerful predictor of student learning (e.g. achievement). Some might argue that many ESS teachers currently use well-organized curriculum materials that embrace core ideas and the practice of science; this would improve their teaching practice. Yet, the use of highly developed curriculum materials provides no guarantee of instructional change (Brown, 2009). Moreover, using curriculum materials does not mean that teachers simply need to *transmit* information to students from them. Rather, teachers need to be able to use curriculum materials flexibly through *transformation* of the core ideas of such curriculum materials into practice by interpreting, evaluating, and adapting them (Brown, 2009). Therefore, poorly qualified ESS teachers may not be able to orchestrate the various instructional, curricular, and technological elements of classroom systems, and to mobilize these tools effectively to foster an inquiry-based science learning environment. The limited learning opportunities significantly influence students' attitudes toward ESS and their choice of ESS as a future career, which then could automatically result in decreasing numbers of highly qualified ESS teachers for the next decade.

Lastly, as one of the survey items used in the quantitative phase, we asked our participating college students the question: 'If you were asked to tutor a high school student taking an Earth Science class, what would you do to help them learn?' We noticed that most of their responses reflected on their own learning experiences, which could be summarized by one student's response, '(I will) *teach what I learned*.' We believe that her response indicated that she would teach not only the contents that she understood, but also the ways of learning and teaching she had experienced in her ESS classroom. In addition to their attitudes toward ESS and their choice of ESS as a future career, students' learning experiences strongly influence their conceptualization of and orientation to how to learn and teach ESS. With this in mind, if

ESS education cannot be successful in recruiting new high-qualified teachers, we will be caught in a vicious circle in which we fail to promote students' scientific literacy, especially Earth Science literacy.

This study aimed to explore in what ways current secondary schooling, especially the small numbers of highly qualified ESS teachers, might influence students' learning of the discipline. Through the multiphase mixed methods research design, we concluded that participating students' ESS learning experience in their secondary schools seemed to have limited or little influence on their conceptual understandings of the discipline. ESS courses in secondary schools should promote students' engagement in the practices of science that helps them understand how scientific knowledge develops, and such direct involvement will provide them with an appreciation of the wide range of approaches that are used to investigate, model, and explain the world (NRC, 2012). Additionally, such engagement will help develop positive attitudes toward ESS that influence not only students' selection of ESS courses (Farenga & Joyce, 1998), but also their career choices (Lietz, Miller, & Kotte, 2002).

The scope of this study does not allow us to fully illustrate students' ESS learning experiences and current state of ESS teaching in secondary schools, as it was focused on limited contexts and employed an indirect approach to explore ESS teaching and learning that relied on participating college students' memory. However, given the goal of science education and recent trends in teaching and learning science, there are several implications for teacher education and future research that can be drawn from this research study, particularly the need for improving school-level teaching of Earth Science. First, this study suggests that ESS teacher education programs may need to take a new approach to increasing the population of pre-service ESS teachers. The lack of prior exposure to ESS materials leads to fewer students with an interest in learning and teaching ESS-related courses and the intent to pursue ESS as a career path (Lewis & Baker, 2010), which likely is driving the declining numbers of highly qualified ESS teachers in secondary schools. Second, this study suggests that ESS teacher education programs should encourage pre-service science teachers to learn about ESS topics, and they should consider ways to provide quality professional developments or workshops that help current in-service ESS teachers not only to enhance their content knowledge, which is a common body of expertise in teachers (Krauss et al., 2008), but also to improve their PCK, including knowledge of instructional strategies, curriculum, and assessment as well as knowledge of students' understanding in ESS (Park & Oliver, 2008).

Disclosure statement

No potential conflict of interest was reported by the authors.

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