Measuring Student Engagement, Knowledge, and Perceptions of Climate Change in an Introductory Environmental Geology Course

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ABSTRACT

This research examines a semester-long introductory environmental geology course, which emphasized climate science using an Earth systems approach and employed a multipronged teaching strategy comprising lecture, movie viewing, class dialogues, and journaling. Evidence of student engagement during various pedagogical approaches (e.g., movie viewing, lecture, and class dialogues) was measured using skin sensors on a subset of student participants in order to gauge student engagement. Results indicated that students are more engaged during movie viewing and dialogue than during lecture, with measurable increases when climate solutions and local impacts were covered. Qualitative data including journal entries and transcripts from student dialogues were analyzed to determine patterns about student climate change perspectives and discourse for which students' self-reflections supported quantitative measures. Measurement of student pre– and post–climate change knowledge, confidence, and perceptions revealed that the combined pedagogical approach supported student learning gains about climate science. © *2014 National Association of Geoscience Teachers*. [DOI: 10.5408/13-111.1]

Key words: galvanic skin response (GSR), skin sensors, active learning, climate change

INTRODUCTION

Research indicates that increases in globally averaged temperatures of just a few degrees in this century will likely cause an increase in the occurrence of drought, floods, and extreme weather and accelerate sea-level rise into the future (IPCC, 2007a, 2007b, 2007c, 2013). Therefore, addressing climate literacy in higher education, especially within courses that house geoscience majors, is important so that future scientists can form evidence-based decisions, develop strategies to address climate change, and communicate with the public effectively about the issue. However, understanding climate change requires grasping systems thinking and understanding of change over multiple spatial and temporal scales (Rebich and Gautier, 2005; Sell et al., 2006; McNeal et al., 2008). Students often have difficulties with understanding radiative processes, water vapor, feedbacks, and the timescales over which climate change can occur (Gautier and Rebich, 2005). Some students believe the greenhouse effect is due to the ozone hole or that greenhouse gases are ''bad'' rather than necessary for moderating Earth's climate (Boyes and Stanisstreet, 1994; Gautier and Rebich, 2005). Furthermore, some students may use localized weather events to draw conclusions about climate change, which occurs regionally and over much longer periods (Choi et al., 2010). In order to assist learners in reasoning about climate change, new ideas must be integrated with preexisting conceptual models (Vosniadou and Brewer, 1992; Bransford et al., 1999; Chi, 2005).

People often default to reliance on their fundamental values and worldviews when learning (McCright and Dunlap, 2011; Leiserowitz et al., 2012). Incoming information that addresses climate change may be rejected upon quick judgment if it challenges deeply held beliefs of an individual or those of the group with which that person most identifies (Kahan et al., 2007, 2012; Kahan and Braman, 2008; CRED, 2009; Rutherford and Weber, 2011; Lombardi and Sinatra, 2013), making teaching about climate change challenging.

Emotions can be tied to engagement, which can strongly influence learning about a topic (Irwin and Wynne, 1996; Ockwell et al., 2009; Weber, 2010; Lombardi and Sinatra, 2013). Pintrich et al. (1993) introduced the concept of hot versus cold conceptual change—cold conceptual changes occur only by engaging the cognitive domain, whereas hot conceptual change involves engaging both the cognitive and the affective domains to bring about lasting changes in learners' preconceptions. Further research has shown that academic emotions play an important role in student learning (Pekrun et al., 2002), and emotional states have been found to be interlinked with cognitive processing (Linnenbrink and Pintrich, 2004; Goetz et al., 2010).

Direct measurement of student engagement in classroom settings and associated affective measures can be challenging. Post hoc questionnaires have been widely used for this purpose. However, such techniques can be limited in scope because of the qualitative nature of the response and because a delayed self-response to an emotional state could bias such data. The advent of affective computing has the potential to circumvent this problem by providing continuous and potentially unbiased physiological data that can open a window into the engagement of research subjects to external stimuli.

Recently, a new methodology for measuring engagement in education research, called galvanic skin response (GSR), has been introduced in science education (Poh et al., 2010). Skin conductance or GSR is the electrical response of skin at low voltage and is usually measured with a pair of

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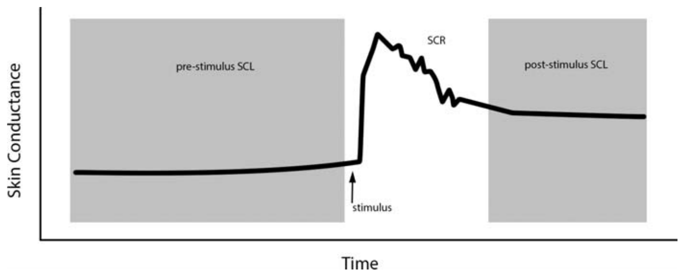

FIGURE 1: Smooth SCL (tonic phase) is interrupted by a rapid rise in skin conductance (SCR, or phasic phase) due to a stimulus. Subsequently, the skin conductance attains a new SCL, which is usually higher than the prestimulus level.

electrodes touching the skin of the palm or the wrist. Skin conductance is a function of the moisture level of skin, which in turn is controlled by sweat gland activity. As sweat glands are a part of the sympathetic nervous system, which also governs our emotional states, it has been postulated that an increase in sweat glands activity signifies both psychological and physiological arousal (Malmivuo and Plonsey, 1995).

GSR is a composite of a slowly varying or tonic component, called the skin conductance level (SCL), and separated by peaks, the phasic skin conductance response (SCR). Typically, SCLs are interrupted by SCRs due to an event or stimulus, and the skin conductance increases sharply and then decays slowly to a new SCL (Fig. 1). SCLs can be used to infer average level of psychological arousal or engagement over a sustained period (hours) or to compare engagement between types of stimuli (e.g., watching movies versus listening to lectures). However, they are not suitable to indicate responses to short-lived stimulus and bursts of activity (e.g., a startling sound or a particularly revolting imagery). For such cases, phasic SCRs are more appropriate. The SCRs are considered to be the responses to bursts of activity in the sudomotor fibers (part of the sweat glands), and the amplitudes of the SCRs are correlated with the number of sweat glands involved in such bursts and the strength of the sudomotor activity in those glands (Benedek and Kaernbach, 2010). In other words, an affective state change, for example, a reaction to a particularly pleasing or offensive sensory stimulus, can be manifested as a SCR (from bursts in sudomotor activity, which controls sweat generation). The SCRs usually show a lag time after the stimulus (1–5 s) and have minimum amplitude of 0.01–0.05 μs (Dawson et al., 2007).

Some issues exist with collecting GSR data, such as the skin-sensing unit worn by the participant potentially introducing difficulty in the data collection process and the often study-specific identification of a meaningful SCR to a stimulus (Dawson et al., 2007). However, these obstacles can commonly be controlled and minimized, especially when the participant's movements are kept to a minimum, reducing the sweat that can accrue in the sweat gland ducts of the skin, which are the primary sites for GSR data collection (Potter and Bolls, 2011).

Skin conductance studies have become commonplace in psychological research due to their reliability in detecting GSR changes that are commonly associated with emotional processing of stimuli such as pictures, music, video games, and film (Potter and Bolls, 2011). Skin conductance methods are often utilized in place of other psychophysiological measures due to the ease of measurement and analysis of GSR data (Andreassi, 2007). As such, skin sensors can form an important part of a larger set of affective computing gears that seeks to monitor biophysical responses such as heart rate, muscle activity, skin temperature, blood volume pulse, electrocardiogram, and respiration (Haag et al., 2004). For example, affective e-learning, a collaborative research project between the Digital Lifestyles Center, University of Essex, UK, and e-Learning Lab, Shanghai Jiaotong University, China, used skin sensors, along with blood volume pressure monitors and electroencephalograph, to chart the role of emotion in learning and how that feedback can be used to improve the learning process (Shen et al., 2009). Several other studies have explored the role of affect in learning by using skin conductance (Dragon et al., 2008; Arroyo et al., 2009; Woolf et al., 2009; Hardy et al., 2013).

STUDY PURPOSE AND RESEARCH QUESTIONS

This pilot study addresses two research questions: (1) How are undergraduate students' engagement levels impacted as a result of pedagogical approach (dialogue, movie, and lecture) about climate change? and (2) How are undergraduate students' understanding, confidence, and perceptions of climate change altered as a result of the multipronged pedagogical approach? We hypothesize that undergraduate students' in-class engagement (as reflected in the skin conductance data or GSR) will increase as active learning is increased in class and that undergraduate students' conceptual knowledge, confidence, and perceptions about climate change will increase as a result of the combined pedagogical approach. In this exploratory study, we set out to determine whether we could measure changes in students GSR when using different pedagogical approaches and then determine whether we could capture which teaching method was most engaging. Furthermore, we wanted to monitor how the combined approaches enhanced student learning about climate change.

METHODS

Context/Background

Twenty-four undergraduate students were enrolled in an introductory environmental geology course at a large southern U.S. university. The average age of the students was 20.9 years, and the group included 5 females and 19 males, with 21 of the 24 students pursuing a geoscience major. The majority of students self-reported as being affiliated with the Republican Party and holding Protestant/Christian belief systems (Fig. 2). Of the 24 students, we collected GSR data on 17 students, and all students completed pre- and postassessments, participated in classroom activities, and completed journaling assignments.

Course Description

The course was an introductory class to environmental geology. The goals of the course included (1) learning the various Earth systems and the major environmental processes that occur in these systems, (2) understanding the basic science of these processes and the evidence of global

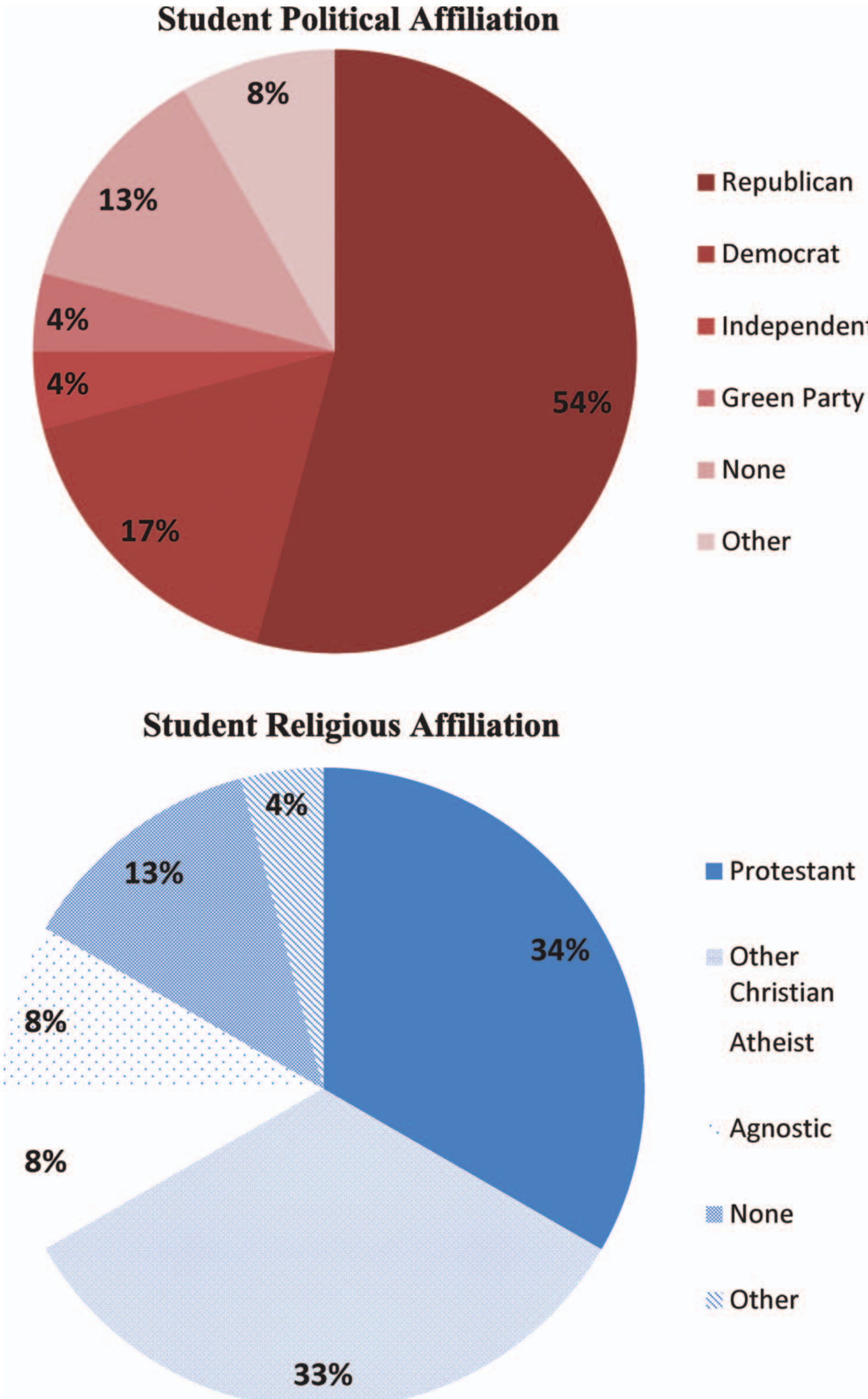

FIGURE 2: Student political and religious affiliations.

environmental change, (3) examining the social debates surrounding the major environmental issues of today, and (4) reflecting, discussing, and communicating about these issues in order to engage in environmental conversations. The specific learning objectives included identification of the Earth systems and their processes, explanation of the scientific underpinnings of major environmental issues facing society today, explanation of the perspectives of various sides of a debate around environmental issues, and communication of the science to others. The course focused on environmental issues that were covered in the context of global change, and information was delivered as it specifically related to climate change. The course was taught using a mixed delivery of teaching in which there were opportunities during lecture for students to discuss content with partners and groups and to watch content appropriate movies. In addition, entire class sessions were dedicated to dialogue and student presentations about the course content.

Lectures were delivered over a 75-min period and consisted of PowerPoint slide delivery with usually one or two active learning segments for students to discuss with their neighbor a question the instructor posed, such as "With your neighbor, share and write down three facts you read about climate change that impacts the southeastern United States (SEUS), from today's reading," "Write down all of the renewable energies you can think of and then share with your neighbor," or "Mitigation or adaption or geoengineering? What are examples of each, and which do you think is the best strategy?" Lecture slides were provided to students after each class period using a class Web portal.

Two movies were viewed during the course. The first, *Earth the Operator's Manual (ETOM),* was viewed over one class period, and the second, *NOVA: Earth in Balance* was viewed over two class periods. For our research, we collected data from *ETOM. ETOM* is a National Science Foundation (NSF)–funded documentary, hosted by geologist Richard Alley and consisting of 12 viewing segments (but all 12 can be viewed without interruption). It begins with Earth's climate history, including carbon dioxide (CO_2) in the atmosphere and the ice core record, and extends to anthropogenic influences, why the military considers climate change a threat, and the many viable sustainable energy options. The globe is traveled from China to Brazil to New Zealand to Spain to Texas, highlighting climate solutions these locales have made.

Devoted class dialogues (40–75 min) were allotted during three class periods to discuss current readings and broader perspectives on climate change topics, although other smaller-scale and more focused discussions occurred during some lecture periods. Students were asked to work in a group no larger than five people and provide a discussion sheet. Students self-assembled their groups and self-assigned roles. One person was to serve in the facilitator role to lead the discussion, and another was to serve as the group note-taker. Before conversations began, students were asked to follow the *Golden Rules of Dialogue* (Nash et al., 2008). These rules included the following:

- Listen to others as we want to be listened to
- No matter how outrageous a point of view might first appear, we must always grant it the right to be heard and understood
- Be willing to find the truth in what we oppose and the error in what we espouse…at least initially

Students were provided guiding questions, such as "Do you think climate change is happening? Why/Why not?" "What evidence do you have for your stance?" "What are the potential impacts of Earth's changing climate?" "What are some of the possible solutions to addressing climate change?" "Who might be the most impacted by a changing climate?" "What is the role of the geoscientist in solving these environmental problems?" Conversations were recorded via a tape recorder. At the end of each dialogue, student groups submitted their discussion notes to the instructor.

Classroom journals were kept by each student. Each month (4 mo total) students submitted a minimum of four entries. Two of the entries described personal reflections that included (1) what they learned about course-related topics, (2) what they want to know about course-related topics, (3) and a description of their perspective or opinion about course-related topics, including any changes that have occurred over the course. The other two entries included descriptions of documented conversations the student had with others, outside of class, about course-related topics.

Data Collection and Analysis

Human subjects' research approval was obtained by the appropriate institutional review boards, and participant consent was obtained for this research project. Thematic analysis of journal responses and transcripts, descriptive statistics, and parametric tests were employed during analysis of the results. Specifics about each of the instruments and methods employed, including trustworthiness, validity, and reliability, are described in further detail below.

Skin Conductance

Skin conductance readings were measured on a subset of students, due to limited number of sensors, during each class activity. Students were randomly selected during the initial class to wear hand sensors. For the following classes, students were randomly selected again; however, those subjects who had worn it for a different treatment were prioritized in order to ensure that at least some of the students would wear the hand sensor during all three treatments. A total of 17 students were measured during the classes, of which 6 wore the device during all three activities (movie, lecture, and dialogue). Students were provided an Affectiva Q Palm Sensor at the beginning of class and asked to put it on immediately. Once the sensor made skin contact, it automatically began collecting data. Students were asked to place it on their nonwriting hand and not to press on the unit or make unnecessary movements while wearing the device. At the end of class, students returned the device to the instructor, who kept notes on the timing of the classroom activity events as the class progressed for later data comparison to student GSR. The data from the Q sensor was then downloaded to the Q software program provided by the sensor manufacturer. Data were collected every 0.125 s over the period of the classroom activities. The large dataset was then plotted, a second-order, 30-s Savitzky-Golay smoothing function was applied in MatLab (Version 2013b), and *t*-tests on aggregated data were performed in the Statistical Package for Social Sciences (Version 21.0). The hand sensors collected not only skin conductance but also temperature and accelerometer data. The external influences during class on student skin conductance outside of the teaching stimuli were recorded. Limited temperature (0.1°C) changes were measured during each class, and students were all sitting in their chairs during each activity, with accelerometer data showing minimal movements. If students physically moved to arrange themselves in student groups, these data were omitted from the analysis to ensure movement was not a factor. As such, temperature and movement were not shown to be external factors on the collected skin conductance data. However, other variables such as student mood and out of class variables can potentially be factors causing individual, day-to-day variances. However, these variables cannot be controlled in such an experiment and thus should be treated as a limitation of this research.

Pre– and Post–Climate Change Content Knowledge, Confidence, and Perceptions

Pre– and post–climate content, confidence, and perception gains were measured using a 17-question Climate Concept Inventory with 10 multiple-choice content items and 7 (1 confidence and 6 perception) Likert scale items. The instrument was developed through modification of existing and applicable items inventoried from the American Association for the Advancement of Science (http://assessment.aaas.org/), the Geoscience Concept Inventory (Libarkin and Anderson, 2005), the Yale Project on Climate Change Communication (Leiserowitz, 2008; Leiserowitz and Smith, 2010), and the Climate Stewardship Survey (Walker and McNeal, 2013) through the ongoing NSF-funded EarthLabs project (http://serc.carleton.edu/earthlabs/index.html). Selected items were then modified and aligned to the broad and systems-oriented climate change learning goals of the EarthLabs climate modules (Ledley et al., 2012). Items were validated through expert climate and curriculum developer review, in addition to item analysis for each question. The reliability of the instrument during testing with 245 upper-level high school students showed an overall 0.67 Cronbach alpha score, a moderate level of reliability and acceptable for most exploratory research (Ravid, 1994). Although the instrument was originally designed for upper-level high school students, we have applied it to introductory college students, as we assumed that this college population was not significantly different from the upper-level high school population. Content-related items loaded on a single factor during principal component analysis showed a discrimination of more than 0.2 and a difficulty from 0.1 to 0.9. Since only one factor was represented for which all items loaded on this factor, the items are interpreted as similar constructs and are thus reliable replicates of the assessed climate change content. Demographic data were collected at the end of the surveys to minimize stereotype threat. Students took the pretest at the beginning of the course, prior to the coverage of the content in class, and again at the end of the course, prior to the final examination. Statistical analysis of pretest and posttest differences were conducted using a paired Student's t-test, and assumptions of the test were satisfied except for the assumption of randomly selected population, because our student population was self-selected to enroll in an introductory geology course that consisted largely of geology majors.

Journal Reflections and Dialogue Transcriptions

Student journals and dialogue transcriptions were analyzed to identify themes that emerged from the responses and identify direct quotes that were representative of the larger group. Furthermore, transcripts established whether students were on task during discussions so that the hand-sensor data could be validated as representative of course content rather than unrelated discussion. Each student group was audio recorded during classroom dialogues, and transcripts were made by a third party. Four monthly journals per student were analyzed for content themes at the passage level, where topics and representative phrases were extracted. Qualitative data can have different trustworthiness than quantitative research that has established validity and reliability measures. However, as the qualitative data were analyzed in this research, researchers took care to continuously compare individual responses to the larger whole to be sure specific examples and themes selected were representative.

TABLE I: Hand-sensor GSR means for each of the teaching approaches.[1]

Student	Lecture Mean GSR (μs)	Dialogue Mean GSR (μs)	Movie Mean GSR (μs)
1	1.63	3.23	5.08
2	4.23	7.13	9.12
3	1.98	5.44	4.59
4	5.73	5.69	9.30
5	13.47	12.89	14.62
6	17.23	13.19	15.55
7	2.26	2.96	N.D.
8	4.84	N.D.	3.40
9	3.45	N.D.	7.44
10	14.19	N.D.	7.97
11	12.09	N.D.	N.D.
12	8.57	N.D.	N.D.
13	12.16	N.D.	N.D.
14	1.88	N.D.	N.D.
15	1.63	N.D.	N.D.
16	2.75	N.D.	N.D.
17	4.81	N.D.	N.D.
Average	6.66	7.21	8.56

[1]N.D. = no data.

RESULTS

Student Engagement

Results from GSR indicated that students were more engaged during movie viewing ($M = 8.56$ μs) and dialogue ($M = 7.21$ μs) than during lecture ($M = 6.66$ μs), where differences among each instructional approach was measured (Table I). Statistical analyses with students engaged in more than one activity showed differences in the engagement level across the three treatments.

GSR time plots indicated that the individual student responses show different patterns among the three teaching approaches (Fig. 3). Lectures illustrated several more engagement cycles, with students alternating between tonic and phasic components more frequently than dialogue and movie-viewing activities. Furthermore, student engagement during lecture appeared to correspond with classroom events, such as group work and topics (e.g., impacts on society; Fig. 4). Whereas approximately 0–30 min represented traditional lecture covering the factors effecting climate change, 30–40 min represented a student in a class activity where students were to work with their neighbor to discuss the previous day's reading assignment, 40–52 min repre-

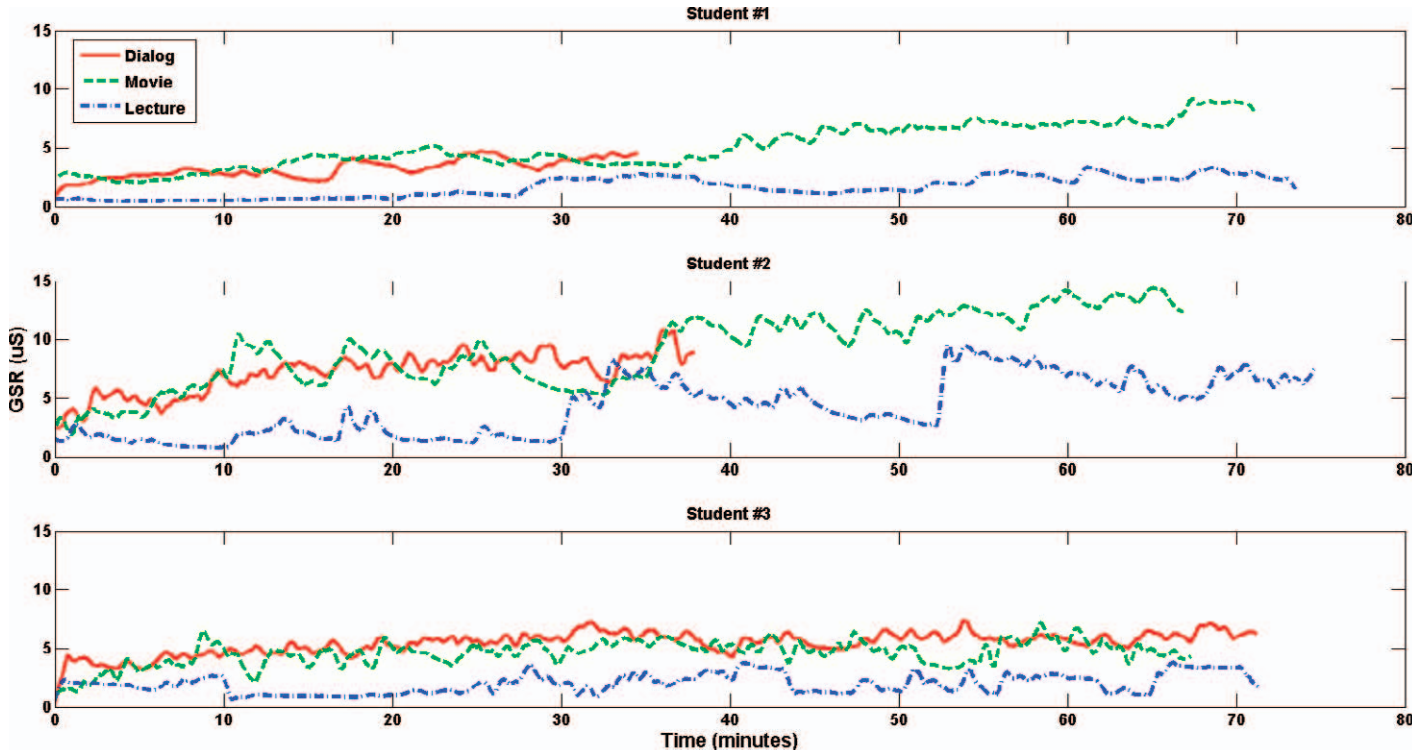

FIGURE 3: Three student example GSR responses for each of the three teaching approaches (lecture, dialogue, and movie). Some dialogue events were shorter (40–70 min) than other classroom activities due to the nature of the activities during different class periods.

sented traditional lecture about the evidence of climate change, and 52–75 min represented lecture that covered the impacts of climate change, including local and regional impacts. Alternatively, during dialogues, student responses appeared to be more constant, with less tonic phases (Fig. 5), where continuous conversation occurred throughout the duration of a class of 0–40 min. During movie viewing, student engagement corresponded to content, similar to lectures; however, the slow upward ramp pointed to a building effect, with a gentle slope, peaking toward the end

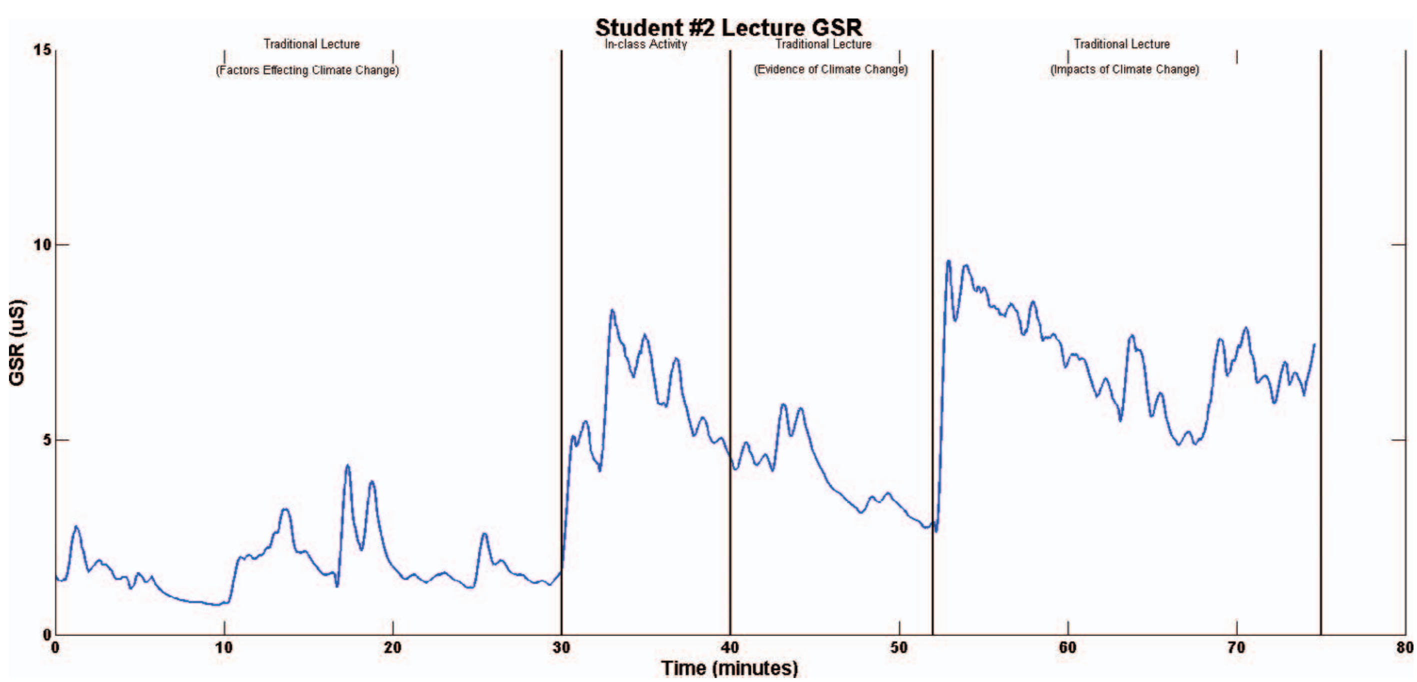

FIGURE 4: Student 2 GSR response for the classroom lecture activity.

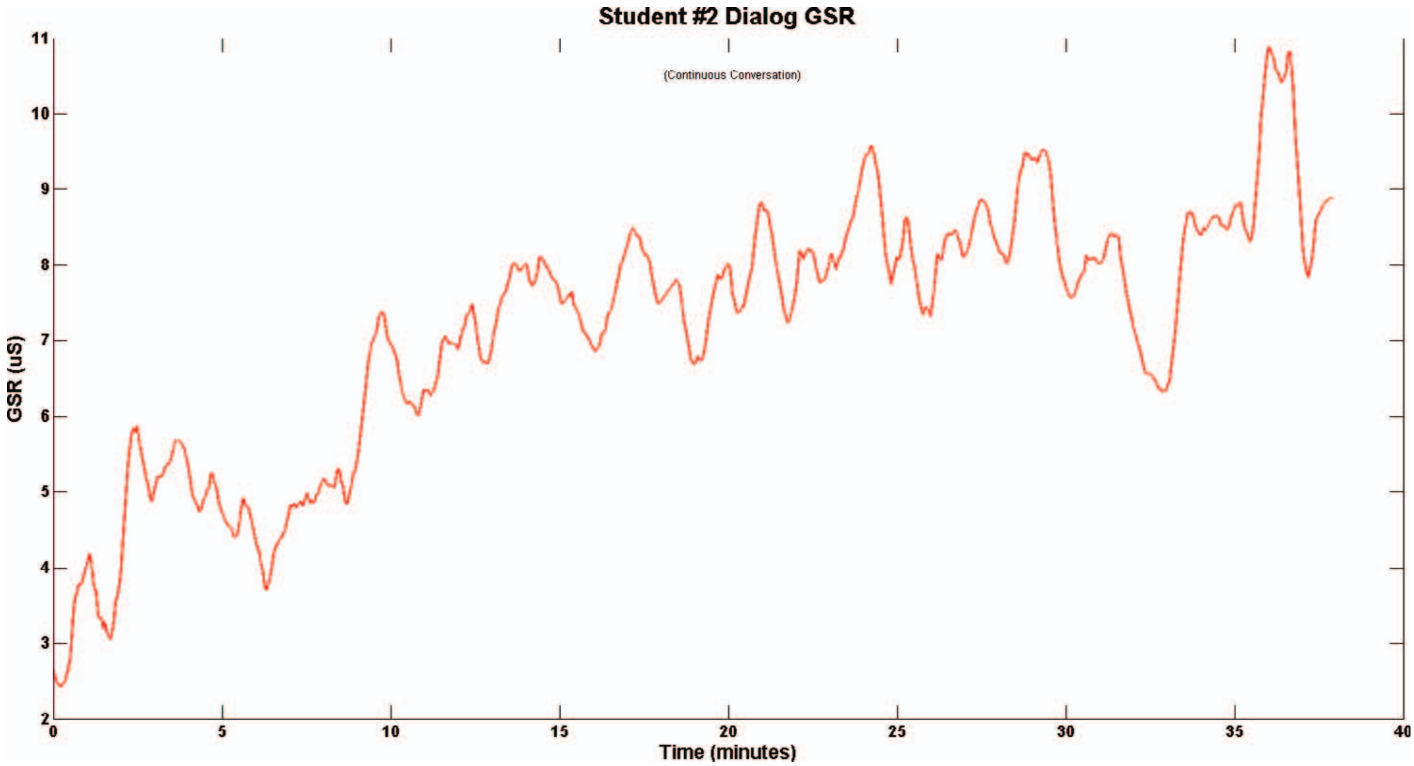

FIGURE 5: Student 2 GSR response for the classroom dialogue activity.

of the movie, which climaxed at the coverage of solutions (Fig. 6). Portions of the movie's content aligned with increases in student engagement, where peaks in phasic responses were evident, such as from approximately 11–13 min (humans and energy), 18–22 min (fossil fuels), 25–28 min (CO_2 and the atmosphere), 35–42 min (China), 42–58 min (renewables and Texas), and 62–70 min (solutions), and valleys were indicated between these time periods. The first

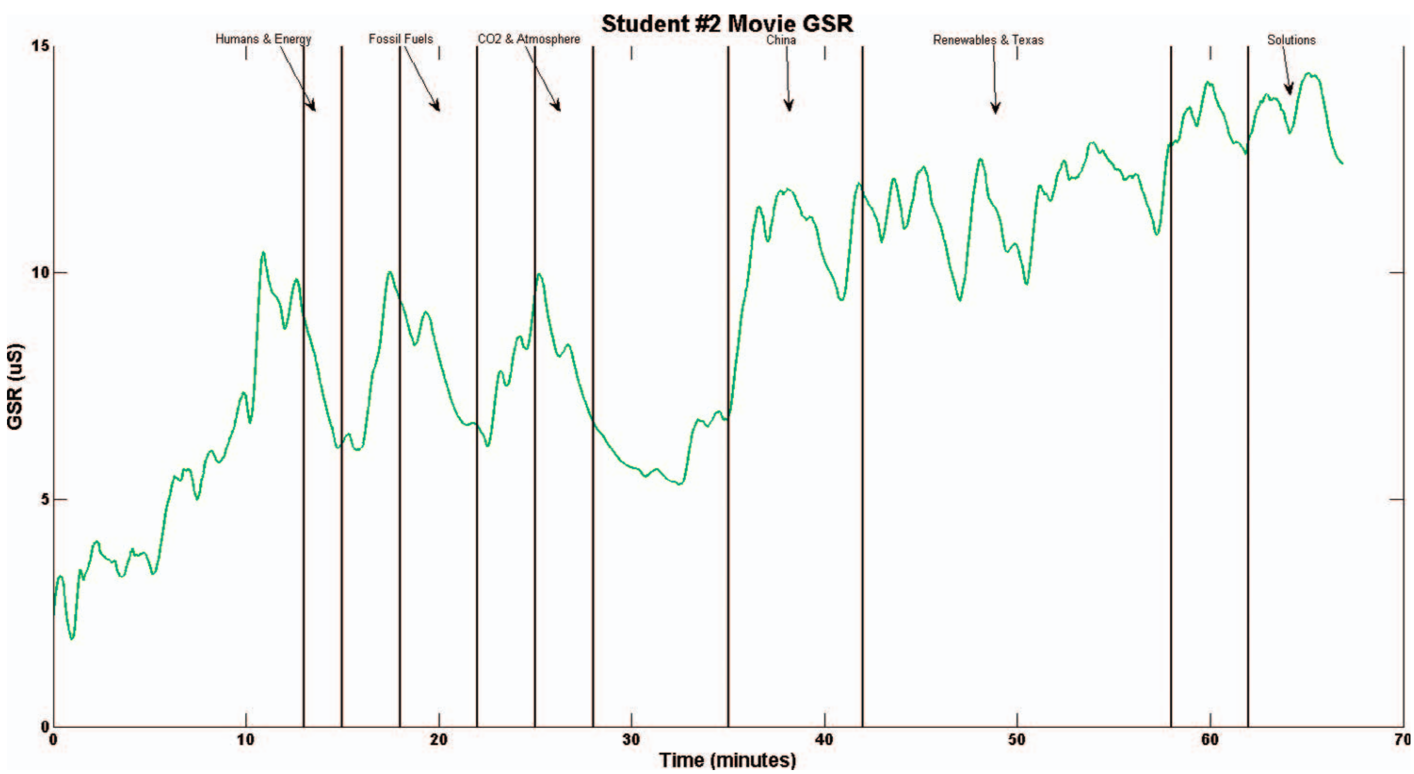

FIGURE 6: Student 2 GSR response for the classroom movie activity.

TABLE II: Student pre–climate change (pre) and post–climate change (post) content scores (%), standard deviation (std dev.), gains (%), and effect size on multiple-choice items.

No.	Question	Mean Pre (%)	Std Dev.	Mean Post (%)	Std Dev.	Gain (%)	Effect Size
Q1	Where are glaciers found today?	52.50	26.20	68.75	21.87	16.25	0.32
Q2	What is a positive feedback loop in a system?	76.47	44.72	93.75	25.00	17.28	0.23
Q3	Which of the following will occur if the amount of sea ice decreases?	70.59	47.87	87.5	34.16	16.91	0.20
Q4	Which of the following factors can change the Earth's cryosphere?	62.50	38.7	79.7	33.19	17.20	0.23
Q5	Which of the following contributes to the transfer of thermal energy from place to place around the Earth?	88.24	34.16	93.75	25.00	5.51	0.09
Q6	How does the temperature of air on Earth increase?	58.82	51.23	75.00	44.72	16.18	0.17
Q7	Which of the following could be a possible cause of the Earth going through a warming period?	57.80	19.83	88.81	27.00	31.01	0.55
Q8	What are greenhouse gases?	23.53	40.31	25.00	44.72	1.47	0.02
Q9	Besides water, what do plants use to make the sugar that is used to build plant structures?	58.82	50.00	80.00	41.40	21.18	0.22
Q10	How has the amount of carbon dioxide in the atmosphere changed since the start of the Industrial Revolution 150 years ago?	88.24	34.16	100.00	0.00	11.76	0.23

approximately 11 min of the class period, students were engaged not in the movie but rather in other, more general classroom activities, such as class attendance record keeping, announcements and reminders about the course, and movie overview.

Student Climate Content Knowledge, Confidence, and Perceptions

Results indicated that students' overall climate content knowledge gains increased 16% on average for the 10 content items (Table II). "Where are glaciers found today?" had a 16% gain, and "Which of the following could be a possible cause of the Earth going through a warming period?" had a 31% gain. These items had an effect size of 0.32 and 0.55, respectively. All other content items showed gains ranging from 1.47%–21.8% and effect sizes from 0.02 to 0.23 (Table II). A Student's t-test for the overall content portion of the assessment, as well as the overall perceptions or confidence portion, showed that the pretest and posttest scores for the class ($N = 24$) were statistically significant ($p < 0.05$).

Results indicated that students' overall confidence and perceptions of climate change were increased by 10% on average for the seven Likert scale (1–4) questions. Four of the seven items showed effect sizes of 0.26–0.59, with gains of 0.28–0.81 (Table III). The four items included "How confident are you in your responses to the previous question set?" "Which comes closer to your view?" (which asked student about whether scientists agreed or disagreed with the state of Earth's climate changes), "Personally, how well informed do you feel you are about how the Earth's 'climate system' works?" and "How much have you thought about the Earth's climate system?" All other items showed effect sizes of 0.12–0.22, with gains of 0.25–0.30. Furthermore, when students were asked whether they were aware of any evidence of climate change and to state the evidence, in an open-ended response question, 56% of the students were able to state at least one example in the pretest; however, 81% stated an example posttest, indicating increased awareness of the evidence of climate change.

Student Dialogues and Journal Reflections

Dialogue sessions and individual journals provided the opportunity to examine more deeply the attitudes and perceptions students held, as well as the self-reflected knowledge gains students made about climate change.

During classroom dialogues, especially early in the course, it was clear groups did not have consensus about the causes of climate change. Some groups were more willing to consider anthropogenic contributions (example 1) than were others (example 2). Some groups discussed how those around them viewed climate change and how being located in the South seemed to influence people's opinions (example 3). All groups accepted that the Earth's climate was changing and could provide evidence of the changes (example 4). Some groups offered solutions that were tied to needed changes of individuals and society (example 5), whereas other groups did not see how any human action would alter the state of the climate (example 6). The groups that described anthropogenic causes also illustrated solutions that required individual and societal action (e.g., examples 1 and 5); however, groups that did not correlate climate change to anthropogenic causes did not consider any potential solutions to the problem (examples 2 and 6), at

TABLE III: Student pre–climate perceptions (pre) and post–climate perceptions (post) scores on Likert scale items (1 = strongly disagree, 4 = strongly agree), standard deviation (std dev.), gain, and effect size.

No.	Question	Mean Pre	Std Dev.	Mean Post	Std Dev.	Gain	Effect Size
Q1	How confident are you in your responses to the previous question set?	2.88	0.5	3.25	0.58	0.37	0.32
Q2	Which of the following statements about global warming over the past 50 years most closely reflects your view point?	2.77	0.86	3.06	0.25	0.30	0.22
Q3	Which comes closer to your view? [Scientist Climate Change Agreement]	3.53	0.63	3.81	0.40	0.28	0.26
Q4	Are you aware of any evidence of global climate change?	2.47	0.81	2.75	0.58	0.28	0.20
Q5	Personally, how well informed do you feel you are about how the Earth's "climate system" works?	2.71	0.48	3.31	0.48	0.61	0.53
Q6	How concerned are you about the possibility of global climate changes?	2.38	0.89	2.6	0.96	0.25	0.12
Q7	How much have you thought about the Earth's climate system?	2.88	0.62	3.69	0.48	0.81	0.59

least at the early stages of the course. Example 4 is an excerpt from Student 2's (Figs. 4–6) group discussion and illustrates the content of the conversation with which the student was engaged. The level of attention in the examples provided were typical of the student conversations and showed that the hand-sensor data collected during dialogue sessions captured on-task conversations.

Example 1

Group Leader: *"Do you think climate change is happening? Why/why not?"*

Student 2: *"The Earth itself goes through a cycle. That's part of the climate change."*

Student 1: *"Right. There's periods of transgression and regression."*

Student 3: *"I think that what's going on right now is natural. But I do think that there's potential for what humans are doing too."*

Group Leader: *"Agree something's happening. We don't know if that's natural, manmade, or just . . ."*

Student 3: *"Maybe, it's both."*

Group Leader: *"It could be both."*

Student 1: *"My personal opinion is that it's an elitist scam to tax us more."*

Student 3: *"If you look through the Earth's crust, it went through the same thing we're going through. Even though there are some manmade emissions in the air, it's still going through the same thing, the same cycles. That's just what I think about that. It's just going to go through that cycle."*

Student 1: *"I don't think that we're the sole cause, but we could possibly be adding to it."*

Student 4: *"I think we're definitely adding to it."*

Example 2

Group Leader: *"Do you think climate change is happening? Why/why not"*

Student 3: *"After all the classes I had here, I know that humans in some senses have changed the climate, but for the most part, it's really just been naturally increasing the heat. In some of my classes they showed us how in the past there's always been a rise and fall in the major temperatures and stuff, and it's just been like a natural process, cycle. We might have played a small part in it, but it's nothing that's going to make the biggest difference. Honestly, I think it's just going to be all natural."*

Student 1: *"My thing is how Venus has real big greenhouse gases? Nobody lives on Venus. That's naturally occurring. If that's naturally occurring over there, how are we making it worse . . . ? We could be making it worse, but it's mostly like he says, mostly natural."*

Group Leader: *"I took an Earth Science class and a meteorology class last semester, and the Earth's climate is changing every second of the day. It has been for thousands of years. That's pretty good evidence that it changes."*

Student 1: *"When you look at history and you're like, 'Oh, there have been multiple ice ages,' obviously climate change is real."*

Group Leader: *"Even the data out there does not make any clear, concise . . . even Al Gore flies around in his nice jets. He's going and preaching about global warming, but is causing it all at the same time."*

Student 2: *"I think they blow it out of proportion a little bit, because blaming the people when, in reality, it is a natural process."*

Example 3

Group Leader: *"Do you think climate change is happening? Why/why not?"*

Lead Student: *"Well, everybody thinks it's happening. It's just … most people think it's happening."*

Student 1: *"Well, most people who are involved in it acknowledge that it's happening, but there are still some people that are actually involved and outspoken that completely deny it at all, and then some people just think the entire idea of global warming is preposterous. They just don't believe there's anything happening at all."*

Student 2: *"My grandparents think that climate change is made up and global warming doesn't exist. They think it's like a fairy tale thing."*

Student 1: *"Especially around here in the South. Apparently [state where student is from] used to have a lot worse winters and you'd think older people would remember that … . I guess it just really takes one bad winter to traumatize them."*

Group Leader: *"Yeah, when temperatures get down into the twenties, you're like, [jokingly] Global warming? What? [laughs]"*

Example 4

Group Leader: *"Do you think climate change is happening? Why/why not?"*

Student 1: *"Yes."*

Student 2: *"Yes."*

Student 3: *"Well that's easy."*

Student 4: *"It's happening."*

Student 3: *"Yeah, it's happening."*

Student 4: *"There's loads of evidence. Like the sea level rise, the melting of the ice caps … the carbon storage in the ice, and the severe thunderstorms."*

Student 3: *"The evidence is everywhere."*

Student 4: *"But like, there's just evidence everywhere."*

Example 5

Group Leader: *"What are some possible solutions to addressing climate change?"*

Student 2: *"I think the issue would be whether or not to use adaptation or mitigation. I think that if everybody knew about it they would know what to think about it. They could have better opinions."*

Student 1: *"I think that's the real problem, really. People just don't have opinions about stuff, one way or the other, because they just get informed by one person, like the news or something."*

Student 2: *"You can make them learn, but you can't make them care."*

Student 1: *"That's true."*

Student 3: *"We could attempt to get people to stop polluting. It would take a lot of convincing."*

Student 4: *"It could go back to the tax for some of the policies we're wanting to do. Like if they tax these people who are releasing more pollution than others, if they tax them more then it will make them want to stop."*

Example 6

Group Leader: *"What are some possible solutions to addressing climate change?"*

Student 1: *"I thought we all agreed that climate change was pretty much natural. I don't understand. I don't know any solutions to the natural world."*

Student 2: *"You can't really."*

Student 4: *"It's dependent on the extent of what you think climate change is, and the cause of it. There are people that think it is only because of humans, and that kind of thing, which I think we're all on agreement where it's probably a natural thing. Granted, we may add a little bit to it."*

The dialogues provided insights about student perspectives that would otherwise be difficult to extract. In conversation with their peers, students were able to state their own perspectives while hearing the perspectives of others, simultaneously incorporating the content (e.g., mitigation, adaptation, and causes and evidence of climate change) received from the course into their conversations throughout the semester. Furthermore, in journaling, they could reflect on their classroom experiences about topics covered in the classroom during dialogues, and the corresponding lectures and movies were often the impetus for the themes students discussed in their journals. The journal entries themes included the following: the water cycle and cryosphere, local issues such as the *Deepwater Horizon* oil spill and impact on the Gulf Coast, water resources management, population growth, conservation of natural resources, recycling and landfills, nuclear and green energy, drivers of global climate change, evidence of climate change, and impacts of climate change. During these monthly journal reflections and conversations with others outside of class, students commented about the amount of knowledge they gained during the course. One student explained, "Just in a few weeks of classes I have learned tenfold of the amount I knew before [about climate change]." Another student stated, "I had thought before about evidence of climate change, but I never really knew exactly how much is out there. Evidence of the heating of the Earth is all around us." A third student added, "I have done some research here and there and heard conversations about climate change, and global warming, but unfortunately, if I am being honest, I could never have educated anyone well on the subject. It is a big deal, but I was very unaware of the details." These comments highlight that the mixed approach of lecture, dialogue, and movies have positively impacted student's self-reflections about their own knowledge about climate change.

Many students recognized that knowledge was not enough and that their newly formed knowledge needed to translate into practice: "It is important to know how I can protect our good Earth. Now that I am moving away from the ignorance is bliss stage, I want to learn quickly and help prevent quickly," "A paradigm shift needs to occur to bring about a new standard of living that has less to do with material wealth and more to do with environmental sustainability goals for ourselves and our society," and "In my opinion, small changes in our everyday lives can make a big difference in changes to our climate." These responses illustrated that students were applying their knowledge to everyday life and saw it as relevant and valuable for their own future actions.

Other students recognized the value in knowing about the issue for their future career: "I believe that these problems are really important, so I find it very important to know all of the bases I need to cover in my future as a geoscientist" and "When I first began this major, my goal was simply to get into an oil company and make the big bucks. This goal has not changed completely but...I can't help but morally disagree with them." This last statement specifically addresses how the perceived value systems between the energy sector and environmental sustainability practices were perhaps an area of emotional conflict for this student. Other students noticed how dialogue activities gave them insights about how important it is to be an informed citizen. One stated, "Sometimes witnessing a classmate's response to the different issues reminds me to learn about the issues before I try to make an opinion." Another recognized the need to communicate with others: "With the knowledge I have gained in this class, I will be able to discuss environmental issues with my friends and family." These responses showed that the students were applying their knowledge to careers and communication activities that they saw as important and valuable.

The dialogue transcript and journal responses illustrated that self-reflected knowledge gains supported the quantitative pre– and post–climate content assessment and pre– and post–climate perceptions findings. Transcript results illustrated that students were on task during these activities, validating collected GSR data. Overall, the combined approach of lecture, dialogue, movie viewing, journal reflection, and conversation with others in and outside of class provided students the opportunity to learn about climate change through a variety of strategies that promoted engagement.

DISCUSSION AND IMPLICATIONS

This study presents GSR as a method to measure undergraduate student engagement in classrooms emphasizing climate science. Results indicated that movie viewing was the most engaging pedagogical technique when learning about climate change. However, it is difficult to know exactly why movies were more engaging then lectures, given that both activities have the student in a more passive role and a receiver of information. It is possible that since movies are designed to be stories, they are more engaging than the typical lecturer. Music in the movies may also play a role on engagement, as well as the visual nature of most movies, which may promote more emotional responses than the other two approaches in this study. It is beyond the scope of this pilot project to determine why these differences occurred, but it is certainly a recommended direction for future research. Student content knowledge, confidence, and perception gains about climate point to the value of the combined pedagogical approach of utilizing movies, lectures, and classroom dialogues when teaching about climate change. Furthermore, student dialogues illustrated how students were trying to grapple with the idea of climate change, what evidence was known and accepted, and whether anthropogenic or natural causes (and solutions) were the dominant mode of operation for the student groups, where differences of opinion among groups were observed. Student reflections of their own learning showed enhanced self-perceived awareness and knowledge about climate change where students were given the opportunity to expand further on topics covered in class, align their own ideas with the content in the course, and discuss these ideas with others outside of class. The multiple pathways of acquiring knowledge (movies and lectures), sharing among peers (dialogue), and self-reflection (journaling) provided a unique learning environment to the students. Both content knowledge and perceptions showed marked improvement, and the journal reflections indicated a deep sense of commitment toward climate change issues. Behavioral change is hard to measure and beyond the scope of this study, but climate change knowledge and awareness can be argued to be prerequisites for individual behavior changes (O'Connor et al., 1999; Bord et al., 2000; Semenza et al., 2008).

One of the limitations of this study was the small sample size. Also, the study was conducted in a classroom setting (less control than a laboratory), where it was difficult to align the exact timing of events with the GSR measures. Therefore, the GSR results presented are coarse. Furthermore, since the course had a high number of students who were geoscience majors, this may prebias the population, which is already scientifically inclined. A different response might occur in a nonmajors course. In addition, student emotional state may change day to day and is difficult to control for in this study, where repeated measures of student engagement occurred over time. However, despite these limitations, this study is the first of its kind to utilize GSR in an undergraduate classroom when teaching and learning about climate change. This study shows that GSR holds great potential in measuring student engagement in the classroom. However, more work is needed to understand the nuances of the approach.

Teaching and learning about climate change should utilize a variety of approaches in order to engage students about the often polarizing issue of climate change. In an era when educators are called to train future scientists to communicate effectively with the public while simultaneously depolarizing the issue, we must recognize comprehensive teaching strategies in order to make significant inroads in building a climate-literate society that is able to grapple with the complexity of the phenomenon and develop practical solutions. Science, technology, engineering, and mathematics education, in general, should use multiple approaches that focus on active (Prince, 2004) and group (Cohen, 1994) learning, and climate change education is no different. This research shows through GSR, for the first time, that there are measurable engagement differences among the differing pedagogical techniques (e.g., movies, lecture, and dialogues) applied in the undergraduate classroom. When these techniques are employed together, significant learning gains can result.

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