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Evaluating the Effectiveness of a School-Based Intervention on Driving-Related Carbon Emissions Using Real-Time Transportation Data

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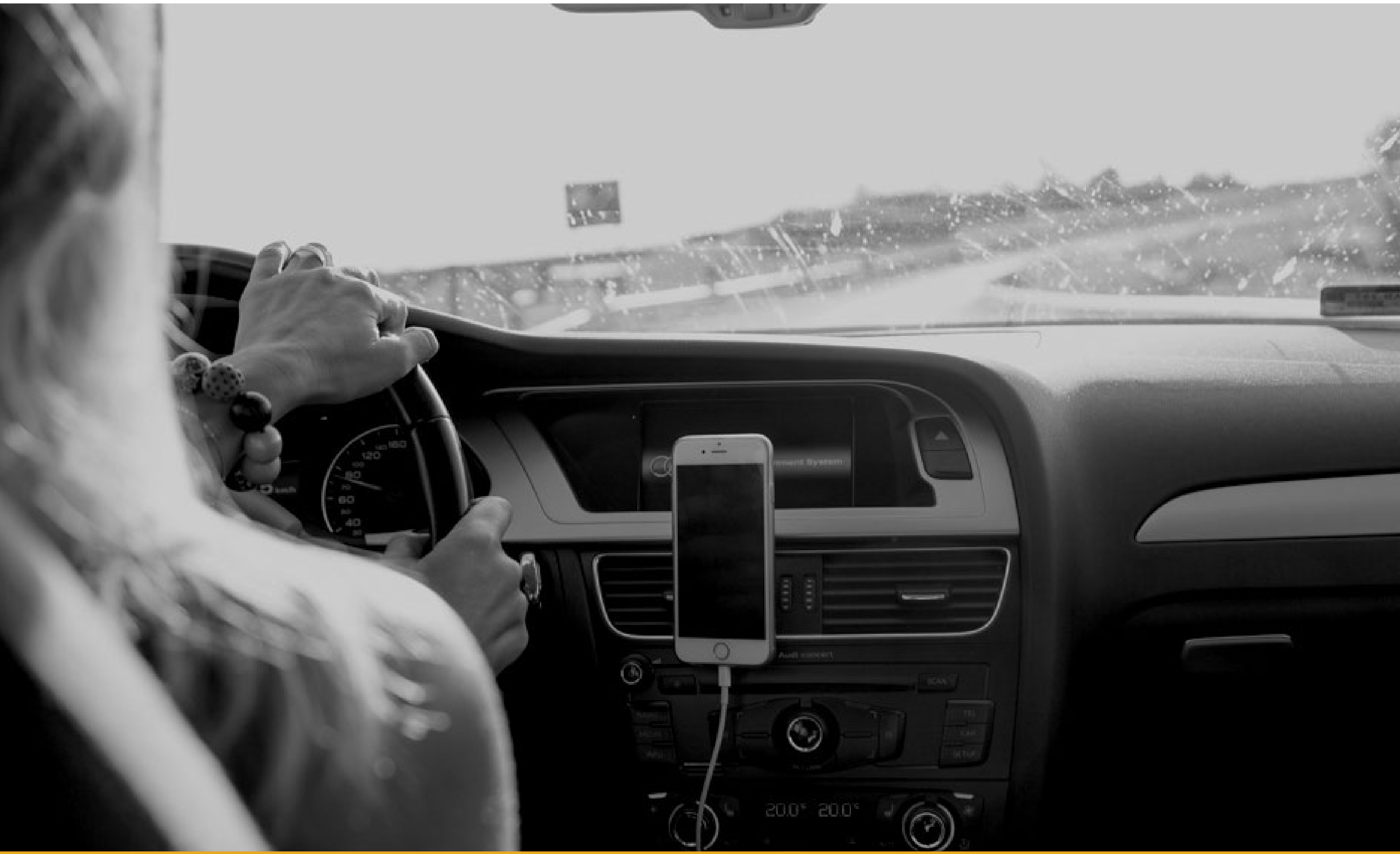

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REPORT 19-19

EVALUATING THE EFFECTIVENESS OF A SCHOOL-BASED INTERVENTION ON DRIVING-RELATED CARBON EMISSIONS USING REAL-TIME TRANSPORTATION DATA

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16. Abstract

The development of tools that can measure the efficiency of individual driving behaviors offers unique opportunities to encourage drivers towards more efficient driving behaviors. As states make progress towards reducing carbon emissions through the adoption of renewable energy for electricity generation, transportation remains the largest sources of carbon emissions. Although numerous local or regional campaigns have encouraged consumers to conserve energy at home and at work, less interest has been shown in encouraging drivers to adopt more energy efficient driving behaviors. In this study, a smartphone application was used to gather driving data (e.g., hard accelerations, hard braking and time over speed limit) within a university course on climate change to investigate whether environmental appeals could encourage more efficient driving behavior in students. The results show that through this intervention, average student driving scores improved by between 2 and 5% in the classes studied, with larger changes found in students who did not initially identify as having pro-environmental attitudes. These results suggest that educational programs and campaigns using real-time data on driving behavior may provide opportunities to reduce carbon emissions.

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EXECUTIVE SUMMARY

Automobile driving is one of the largest contributors to California's greenhouse gas emissions as well as a major source of pollutants contributing to air quality concerns. Various strategies have been employed by local, state and federal agencies to reduce emissions, including: educational programs that encourage behaviors such as public transit use; carpooling; and the promotion of lower emission vehicles. One strategy that has not yet been well tested is the implementation of a device-based approach in schools, with student drivers encouraged to drive less and more efficiently through access to real-time transportation data. The program whose trial implementation is described in this research aimed to develop a smartphone application that helps individuals monitor and track their driving patterns and behaviors. This tool was used in conjunction with a unit on transportation in a university-level class on global climate change. Data from the entire class was aggregated and tracked using the tool. Students studied their own driving behavior for at least two weeks and then designed and implemented plans to improve their Green Driving Score, which incorporated: number of hard accelerations; number of hard brakes; and number of seconds spent over the speed limit, with a higher total score corresponding to more energy-efficient driving. The results of this intervention, which was conducted in three general education science courses at San José State University (SJSU), provided insights into the challenges and opportunities of such an approach.

The study procedure was as follows. (1) Through partnership with an existing phone-based driving technology company, Zendrive, the research team developed, tested and implemented a school-based online platform with which both students and the teacher could monitor and track their own and other students' driving behavior. (2) An existing climate-change curriculum was adapted, and investigated the usefulness of the platform for facilitating behavior change; this investigation included an observation period, during which students would study their own driving behavior, and a conservation period, during which students would attempt to implement changes to their driving behavior.

The results were as follows. (1) After implementation of the curriculum, average student Green Driving Scores were found to have improved by between 2–5% in the classes studied. (2) Student's feedback and reflections provided a number of recommendations for technological modifications that might improve the educational and behavior-modification potential of such an intervention. Given these results, the authors anticipate and recommend further research into developing educational programs that can leverage existing sources of real-time data to reduce transportation-related carbon emissions through more efficient driving.

I. INTRODUCTION

Climate change is arguably the most significant social-environmental issue facing the planet today.[1] Without significant changes in emissions of heat-trapping gases over the next few decades, global temperatures will continue to rise, and impacts on coastal populations, agriculture and water availability are projected to produce extreme social, economic and environmental impacts by the end of the century.[2] The Paris Agreement, announced in December 2015, has now been signed by 177 nations agreeing to various mitigation measures to reduce the rise of global temperatures.[3] California has made strong commitments to reducing carbon emissions with a goal of cutting emissions 40% below 1990 levels by 2030.[4] Although progress is being made in reducing emissions from electricity generation, by far the sector with the highest levels of carbon emissions is the transportation sector, which accounts for 41% of all emissions, while the industrial and electricity sectors are responsible for 26% and 16% respectively.[5] Reducing emissions from transportation is challenging in part because it involves human behavior and decision making. For California to reach its target emission-reduction goal, significant changes in transportation infrastructure (e.g., more efficient automobiles and additional public transit options) will be needed, including some level of behavior change.

The goal of the project is to use a behavior change model of environmental education together with access to real-time transportation data to create a school-based intervention that promotes reductions in driving-related carbon emissions. Building on existing experience in using energy tracking technologies and education, the research's objectives in outline are:

- *To evaluate the challenges and opportunities of using real-time transportation data in an educational environment.* Although education has been moving quickly to embrace some new technologies, schools still face various challenges associated with data access and personal privacy.

- *To understand the role of real-time transportation data on student motivation and engagement.* Student motivation is a central component to student learning, and the use of real-time personally relevant data has the potential to create an engaging learning experience.

- *To evaluate the effectiveness of the designed intervention on individual driving behavior and transportation-related carbon emissions.* It is important to investigate the level to which this intervention affects attitudes and behaviors, and to identify barriers that might limit the potential of such a design.

In Section II, a literature review will describe earlier work in this area and show how this research builds on established projects and literature. Section III will then describe the methods of this work, including: the development of the technology; the development of the curriculum security, privacy and data collection processes; and the data analysis and visualization processes. In Section IV, the analysis and results will be presented followed by conclusions and recommendations in Section V.

II. LITERATURE REVIEW

In 1992, the United Nations Convention on Climate Change stated, “Education is an essential element for mounting an adequate global response to climate change”.[6] Although few would argue against the importance of education in providing informed responses to environmental problems, most mitigation measures focus on actions whose success can be easily measured, such as improvements to automobile efficiency or transitions to renewable energy sources. Education, in contrast, does not get as much attention as a climate solution mechanism, in part because of the challenges associated with documenting the effectiveness of educational programs that often center around attitudes and behavior change.[7] The focus of the research reported here is to evaluate whether an educational intervention, designed around access to real-time transportation data, can produce reductions in carbon emissions.

Education has been found to be one method for promoting behavior change, but only when the educational experience is well-designed.[8] The environmental education literature offers some insight into the connections between education and behavior change, and it also provides guidance on how to encourage pro-environmental behavior.[9] The intuitive idea that knowledge should be enough to lead to awareness and then to action has been countered by the findings that increased knowledge and skills are not necessarily enough to change behavior.[10] The literature suggests that concerning pro-environmental behavior, more personal factors such as a deep connection to nature, personal relevance of the issue and feelings of personal empowerment and agency are important for contributing to successful behavior change programs (Figure 1).[11,12,13] Thus, using real-time transportation data from individuals or their families may support the personal empowerment and agency component previously seen in successful behavior-change programs.

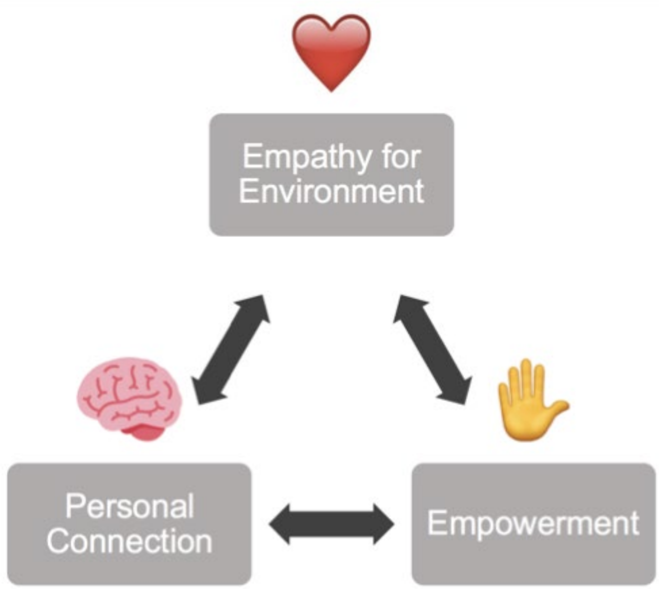

Figure 1. Behavior-Change Model. The behavior-change model being employed for these educational materials includes a focus on the heart (empathy for the environment), the brain (personal connection) and hands-on skills (empowerment).

Over the last few years, the research team led by Eugene Cordero, based at San José State University (SJSU), has been involved in projects related to methods of reducing carbon emissions under a university-based research initiative called Green Ninja. Although this work included a study describing how the adoption of hybrid online courses could reduce transportation emissions for university students,[14] the main focus of these projects is on youth education and behavior change. Through the Green Ninja initiative, this work has led to an understanding of the importance of behavioral change tools that include a focus on (a) personal engagement,[15] (b) societal relevance,[16] and (c) measurements of individual personal impact using relevant real-time data.[17] These key insights have shaped the present research's goal to develop a tool that estimates the impact of personal transportation decisions on emissions. Although online calculators for estimating transportation impact have been used in educational settings,[18] to date no real-time assessment tool has been developed for educational environments.

In 2014, Cordero's research team developed a tool for measuring and tracking personal energy use through home smart meters, which are common in most parts of the US The Green Ninja Smart Energy Tracker is incorporated in a multi-week curriculum, in which students apply engineering methods to design and implement an energy reduction plan for their own home. The Tracker is an online tool where students enter their household energy data (electricity and natural gas usage), and the teacher uses this aggregated data to help students learn about home energy use. In two projects funded by the City of San José, the Green Ninja Smart Energy Tracker program documented reductions in home energy use of more than 10% (n>800) of middle school and university student participants). Figure 2 provides an example of the average energy use of middle school students in a class during both a baseline period and a conservation period. Students examined home energy use during a baseline period and then implemented energy conservation behaviors (e.g., changing to more efficient lighting, hanging clothes out to dry instead of using a dryer) during a conservation period. The teacher was able to monitor all the data from their students, and each student was also able to see their own data and the anonymized data of other students in their class. This intervention not only led to documented reductions in energy use, but also led to shifts towards more pro-environmental attitudes and beliefs in participating students.[19]

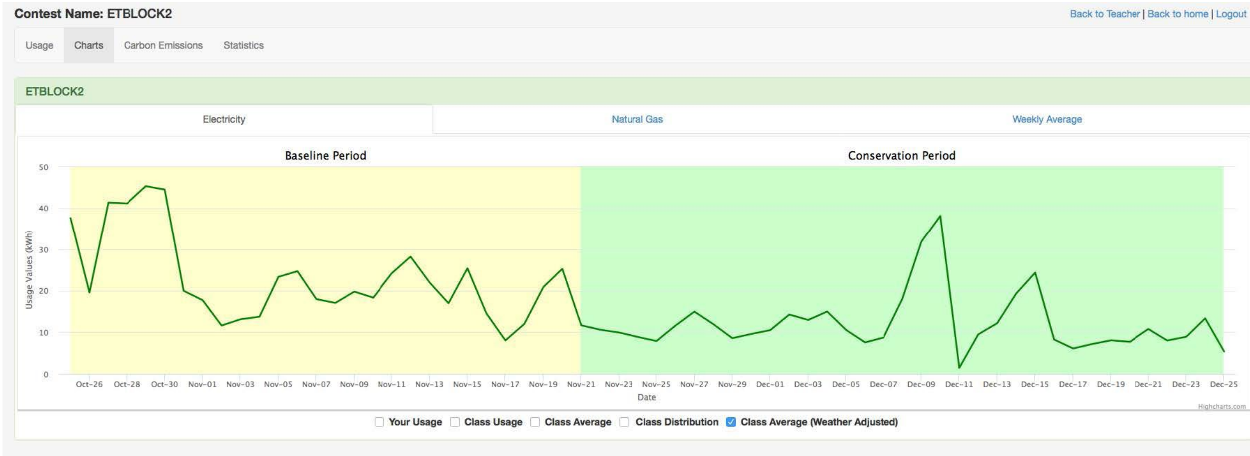

Figure 2. Green Ninja Smart Energy Tracker. This example shows the average electricity use for a class of middle school students (n=20) during the baseline and conservation periods, taken from the Green Ninja Smart Energy Tracker.

Through the development of low-cost devices and smartphone technologies, the real-time monitoring of driving behaviors has become much easier than in the past.[20, 21] Smartphone applications coupled to automobile adapters, such as the Drivebot (described in promotional material as a 'Fitbit for your car'), now make it possible for driving data to be monitored and tracked. Typically, the types of data gathered include miles driven, speed, frequency of hard acceleration and hard braking, and speed during turns. Naturally, this data can be used for many different purposes including fleet management, personal safety, diagnostic engine analysis, insurance reports and improving fuel efficiency. Such data has been used in various studies[22, 23] and has the potential to be used to modify personal behavior. However, it does not appear that such technology has yet been used in a university setting as a tool for monitoring and reducing driving-related carbon emissions.

III. METHODOLOGY

For the present work, the authors collaborated with a phone-based application provider called Zendrive (https://www.zendrive.com), which specializes in providing automobile fleets used in business and government (e.g., delivery services and maintenance operators) with access to real-time transportation data. For this service, the user simply downloads an app on their smartphone and then, using the phone's onboard GPS and gyroscopic sensors, driving information is provided to the phone and to a central server. The system reports both distance driven and "Driver score," the calculation of which takes into account: frequency of hard brakes; frequency of rapid accelerations; and time spent over speed limit (Figure 3). The service offers fleet operators the opportunity to monitor driving behavior at an individual and fleet level for use in driving coaching and fleet management. Zendrive also provides an Application Programming Interface (API) that allows third-party developers to access consented customer data. It was through this API that the research team was able to gain access to the driving data of the student participants.

At the time of this research, Zendrive only had their application available for iPhone users, with a future release of an Android application planned for a later date. Although the research team knew this was not ideal, there were no other applications available that provided a suitable API to gather student data.

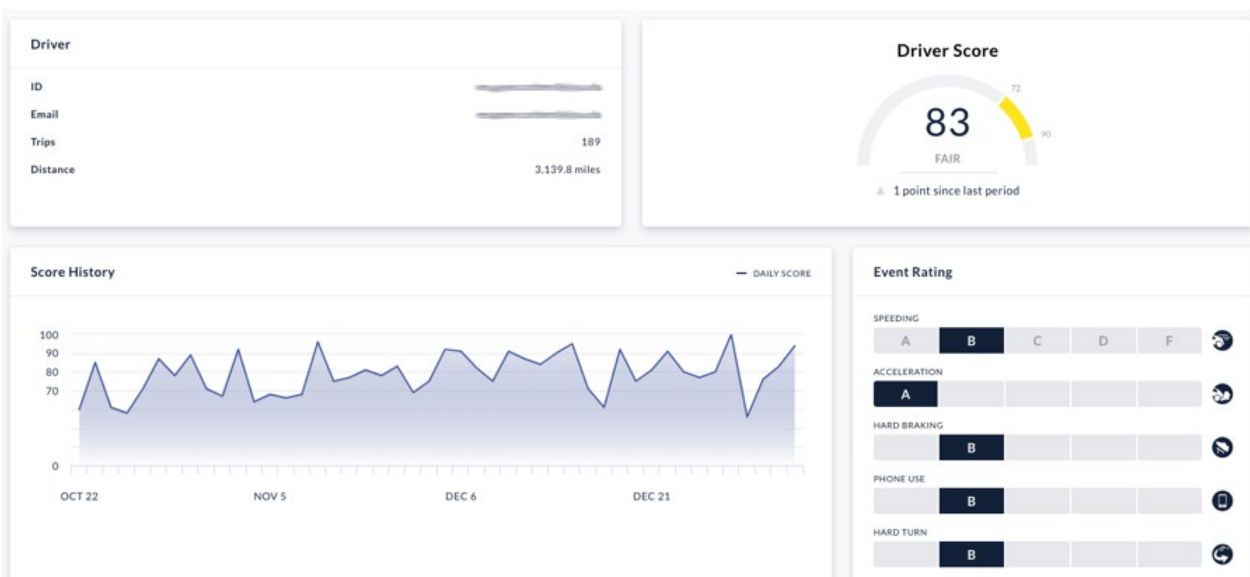

Figure 3. Zendrive Admin Dashboard. This example shows the Zendrive admin dashboard for one user, with Driver Score and other driving data.

The next three sections describe the general methodology of the applied research: (1) Technology; (2) Curriculum Development and Implementation; and (3) Survey and Evaluation.

TECHNOLOGY

The key innovation developed for this research is a web-based method for measuring and tracking personal transportation data, including an overall score for driving efficiency. An existing third-party smartphone application was used to evaluate the potential application of such technologies. Although indices for measuring the environmental impact of driving have been developed before, none prior to this research had been used in classroom environments. The development of this technology for classroom use required three key technical stages, described below: a) Data Collection; b) Data Analysis and Visualization; and c) Security and Privacy.

Data Collection

In this part of the research, two general methods for accessing driving data were explored. The first method uses a device installed in the car, such as that offered by Automatic.com, and the second method is a phone-based system, such as that offered by Zendrive.com. After an evaluation phase, the Zendrive phone-based system was decided upon. Although device-based technologies may provide a richer data set, the existing APIs that would allow the development team to gather the required datasets were not well developed for third parties. However, after discussions with Zendrive, who already have a dashboard for fleet operators, an agreement was developed for a cohort of drivers to use the Zendrive app, and for the team to have access to a new Zendrive API to collect and visualize the data streams of the cohort.

Data Analysis and Visualization

Once data streams were built on a server, the development team explored ways of organizing this data with a user-friendly interface, both for teachers and students. After working with Zendrive software engineers, the research team developed a software system using Amazon Web Services, and utilized various open-source tools such as MySQL and Python to manage, visualize and analyze the data. The system downloaded driver data every day, and calculated a “Green Driving Score” using the individual scores provided by Zendrive (i.e., frequency of hard brakes, rapid accelerations, and time above speed limit for each driving session) and the study’s algorithm then used this data to weigh the individual driving session scores based on total time driven per day. The calculation of the daily Green Driving Score is:

$$\text{Green Driving Score} = (A^{*}.33 + B^{*}.33 + C^{*}.33), \text{ where}$$

A = Hard Brake score

B = Hard Acceleration score

C = Time over Speed Limit score

The values of A, B, and C are time-weighted from each of the individual driving sessions during a day, and range from 0–100, where the higher the score, the more efficient the driving behavior.

The visualization of the system was designed to enable both teachers and students to have easy access to each of the data streams. Figure 4 shows a screen shot showing the distribution of daily scores and the class average score of each student from one of the participating sections. Other tabs would show data and averages of total distance, hard brakes, rapid accelerations and time spent over the speed limit.

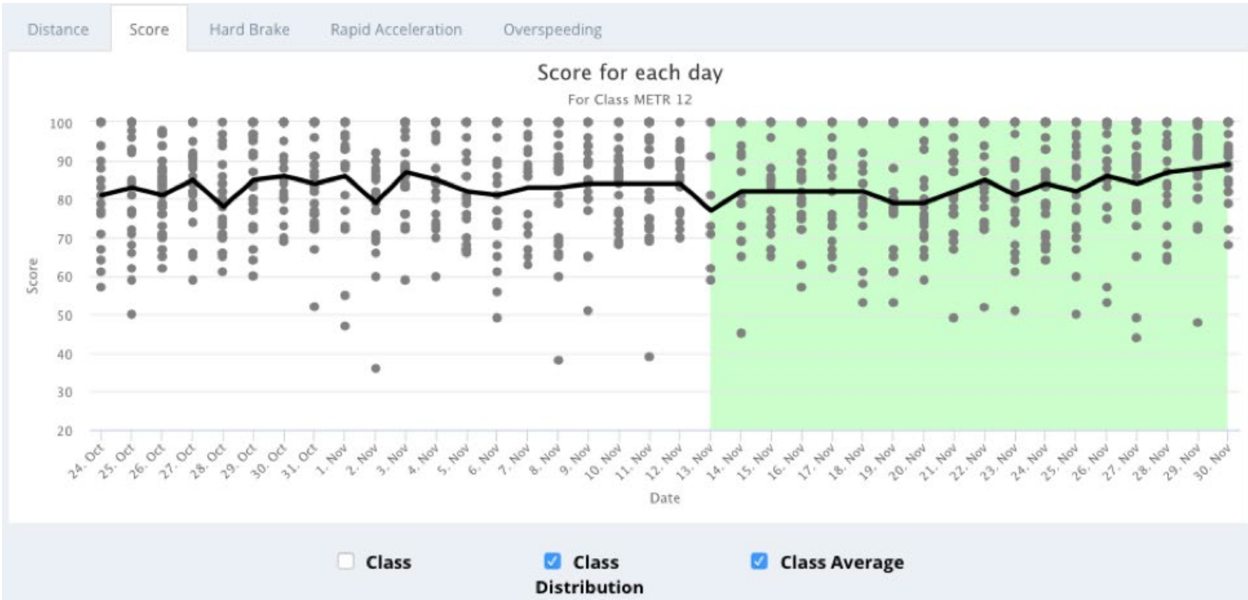

Figure 4. Transportation Dashboard. This example shows a screenshot from the driving application for the METR 12 class, showing the daily Green Driving Score, whose calculation incorporates the frequency of hard brakes, rapid accelerations and time spent over the speed limit, such that the higher the score the more energy-efficient the driving. The evolution over time of the classroom distribution is shown, together with the classroom mean as the bold black curve. For the dates with the white background, students were monitoring their driving behavior (i.e., baseline period), while the dates with a green background represent a period when students were trying to improve their driving behavior (i.e., conservation period).

Security and Privacy

The research team recognized that asking individuals to share their personal driving data might raise concerns about access and privacy. The data was therefore stored on secured servers, and only stored the field listed (name of student, distance, number of hard brakes, number of rapid accelerations, and time spent over the speed limit), but not any of the GPS information about location. It was also ensured that the data was encrypted as it was passed from the API to a server. Even so, privacy concerns may have been significant, as only 50% of students opted to provide the research team with access to their data.

CURRICULUM DEVELOPMENT AND IMPLEMENTATION

A curriculum focused around energy, transportation and climate was adapted from earlier climate change courses taught by Eugene Cordero. The curriculum spans several weeks as students learn about the connections between transportation and climate change, and monitor and track their own transportation impact using the phone application and website. Using a methodology modeled on that of a previous study on home energy conservation,[24] students tracked their driving day during a baseline phase, spanning about two weeks depending on the schedule of class meetings. During this period, students were asked to monitor their own driving data and look for patterns in their driving behavior, and in the behavior of other students. Up to this point, students were not aware of any plans to improve their Green Driving Scores; rather, they were told that the data was only being used to study driving behavior. However, following this phase, students were then asked to develop and implement a plan for how to improve their Green Driving Score over a conservation period. During the conservation period, students were asked to log into the website every week to see how they were doing, and to also look at the classroom average.

During the fall of 2018, a pilot of the proposed curriculum was implemented in three SJSU general education classes: one section of METR 12 (Global Warming: Science and Solutions) taught by Eugene Cordero, hereafter referred to as 'Eugene', and two sections of METR 112 (Global Climate Change) taught by Diana Centeno, hereafter referred to as 'Diana'. A survey and letter were given to students who were able to opt in to participate in the study and provide consent. Each student who decided to participate was given the smartphone application for free. Staff member, Huong Cheng, went to each class to discuss participation in the research and to clarify any student questions or concerns.

SURVEY AND EVALUATION

Two methods were employed to analyze and evaluate the success of this pilot project. The first was to use student surveys to measure interest and attitudes about climate change, climate solutions and transportation behaviors; a copy of the survey is provided in Appendix A. The authors used an already-established survey and protocol registered with SJSU's IRB board (tracking number F15035) that had been used with over 300 students in the 2016/2017 earlier research; modifications were made to this already-existing survey to better suit the focus on transportation. The second method of evaluation was through the analysis of data collected from the smartphone app. These two methods' results are discussed in more detail in Section IV, Analysis and Results.

IV. ANALYSIS AND RESULTS

Of the three university classes that participated in the research, approximately one third of the students consented to participate in the research both by providing answers to the survey and allowing the research team to have access to their driving data. Although a member of the research team visited each class to answer questions about how the data would be handled and to address any privacy concerns, the number of participating students was smaller than the research team had initially anticipated (n=37). A few factors might have contributed to this. One factor was that the driving application was only available for iPhones, so students with Android or other smartphone operating systems were not able to participate. From an informal survey taken during class, it appeared that about 30% of students did not own iPhones. Another factor was that many of the students did not regularly drive. This was especially true in Eugene’s class, where most of the students were first- and second-year students; at SJSU, first-year students who do not live locally are required to live on campus. Although the number of participants was lower than expected, the results nevertheless provide valuable insights into the value of such an intervention.

SURVEY ANALYSIS

The 19-item survey was completed by all consenting students in the participating classes (n=37) at the beginning of the semester. Although the classes cover similar science topics (i.e., climate change science and solutions), the students in Eugene’s class were typically first- and second-year students while Diana’s students were typically third- and fourth-year students.

In both classes there was agreement (i.e., over 80%) that climate change is happening, is due to human activities and will harm future generations if left unchecked. About 70% of students understood that a consensus among scientists existed about the causes of climate change, and over 80% of students reported that they were interested in learning more about energy and climate change. Over 70% of students also reported that they had personally experienced the impact of climate change. In terms of solutions, all participants agreed that individuals should do more to reduce the impacts of climate change, most (over 70%) believed they were aware of actions they could take to reduce carbon emissions, and most (over 70%) believed that individual actions could make a difference. While over 90% of the students said that they were aware of the role that transportation plays on carbon emissions, only approximately 40% reported regularly practicing green driving behaviors, although the survey question did not specify any particular type of behaviors.

The survey also identified some differences between Eugene’s class and Diana’s class. In Eugene’s class, over 70% of students looked for opportunities to walk, bike or take public transit, while in Diana’s class, only 30% did. In Diana’s class, 70% of students disagreed with the proposition that technology could provide solutions to climate change without big individual changes, while fewer than 25% of Eugene’s students disagreed with that statement. Otherwise, most students in the different classes responded in similar ways to the survey.

The survey offered insights into the students who participated in the driving application study. In particular, it showed that the students believed that climate change is happening, is affecting their lives, and that personal actions are needed to help reduce emissions. Although students seemed to have different transportation behaviors between the two types of classes, they seemed to share a common understanding of the role that transportation has on climate change, and general interest in the environment and solutions to climate change. These results suggested that the student participants would find the intervention interesting and that they would be willing to take actions to reduce their transportation-related carbon emissions.

DRIVING DATA

An analysis of the Green Driving Score data from two sections in Diana's class and from one section in Eugene's class is shown in Figure 5. Results from the baseline and conservations periods are compared for the average Green Driving Score in the two classes.

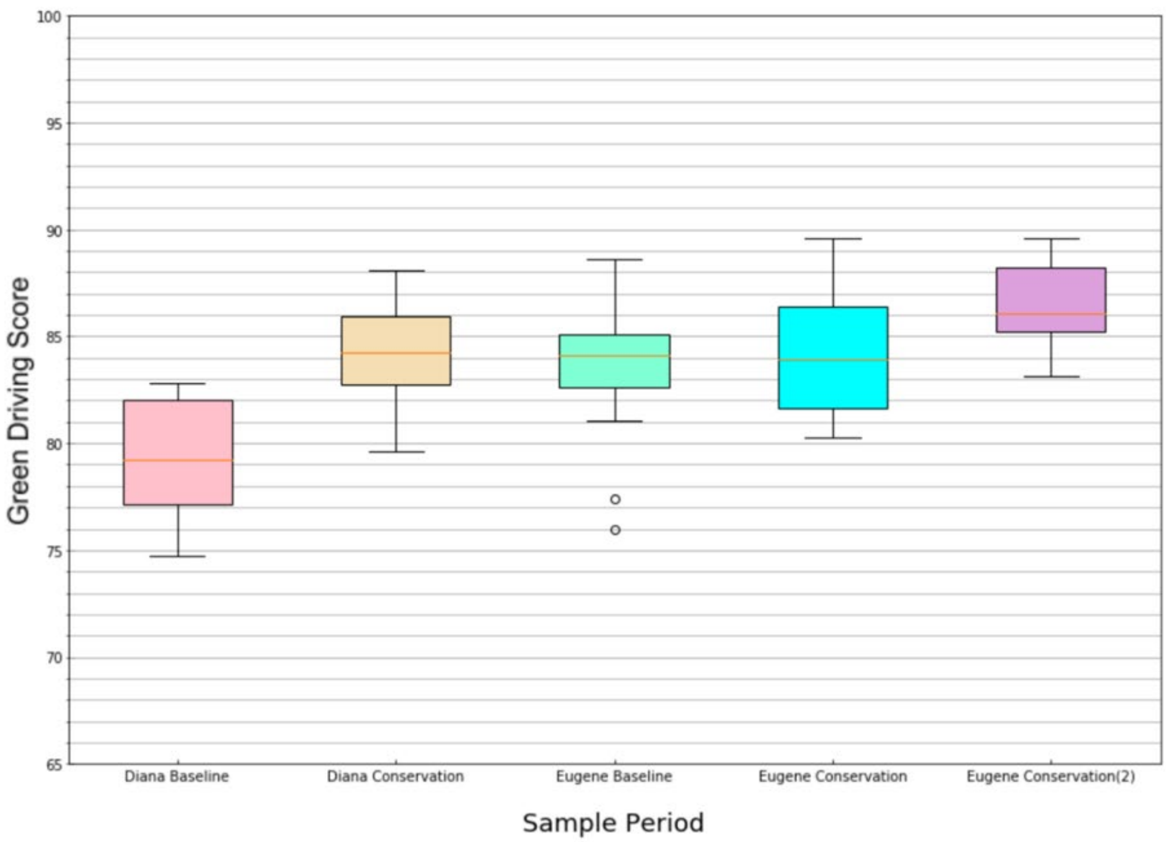

Figure 5. Results of Average Green Driving Score. This plot compares the average driving score during the baseline and conservation periods, both for Diana's and for Eugene's classes. This box and whisker plot shows the median value, the upper and lower quartiles (box), and 1.5 times the interquartile range (whiskers), with outliers marked as circles.

In Diana's class sections (n=17), the median score of all students went from 79 during the baseline period to 84 during the conservation period. In Eugene's class (n=20) the median score changed only negligibly from the baseline to the conservation period, although the spread of data did become wider. However, in Eugene's class, he issued a second, additional week-long conservation period when it became clear that students hadn't made improvements; during this second conservation period (labeled Eugene Conservation(2)), the median score went up approximately two points, from 84 to 86. The shifts toward improvements in Green Driving Score following an additional reward offer (i.e., burrito lunch if classroom average improved) suggested that such appeals may have been somewhat effective during this intervention, although there are a number of uncertainties that remain, as discussed in the Uncertainties section below. Of the changes that were recorded between the baseline period and the conservation period, an analysis of the three components of the Green Driving Score show that improvements in Diana's class were due to fewer hard accelerations, while in Eugene's class improvements were due to reductions in time spent over the speed limit.

Figure 6 shows how student Green Driving Score data was then further explored by dividing students into two groups based on their environmental attitudes as measured by the pre-survey: the top half of students who most positively answered questions such as 'I care about the environment' or 'I regularly look for opportunities to walk, ride a bike or take public transit' were grouped into the pro-environmental category, and the lower half were grouped into the non-environmental category. The same analysis as done for Figure 5 was then repeated for each of these groups of students. The purpose of this was to see if students who exhibited pro-environmental attitudes were more likely to produce improvements in their Green Driving Scores than were students who exhibited non-environmental attitudes. As seen in Figure 6, measurable changes were found in Diana's class, which showed a six-point improvement in Green Driving Score for the pro-environmental group (labelled >median) and a nine-point improvement for the non-environmental group (labelled <median). Although there were improvements in both cases, the pro-environmental group had the greater difference compared to the non-environmental group. In the case of Eugene's class, there were also differences observed between the two groups. An 11-point reduction in Green Driving Score was found for the pro-environmental group (labelled > median), and a 4-point improvement in Green Driving Score for the non-environmental group. And during the second conservation period, after a reward-based appeal was given, there was a 2-point improvement (over the previous conservation period) for the pro-environmental group, and a four-point improvement (over the previous conservation period) for the non-environmental group.

These results, although only based on a limited sample, offer some possible conclusions. It seems that students who already had pro-environmental attitudes did not respond as favorably to the intervention as students who did not have strong environmental attitudes. Perhaps the focus on driving as the central activity allowed students who typically have not aligned themselves with environmental behaviors (e.g., biking, bringing your own water bottle, recycling) to feel more inspired to participate through their driving actions. Although this would require additional analysis, the idea that driving-based education campaigns may best reach people who do not traditionally align with environmental values is intriguing and worthy of future study.

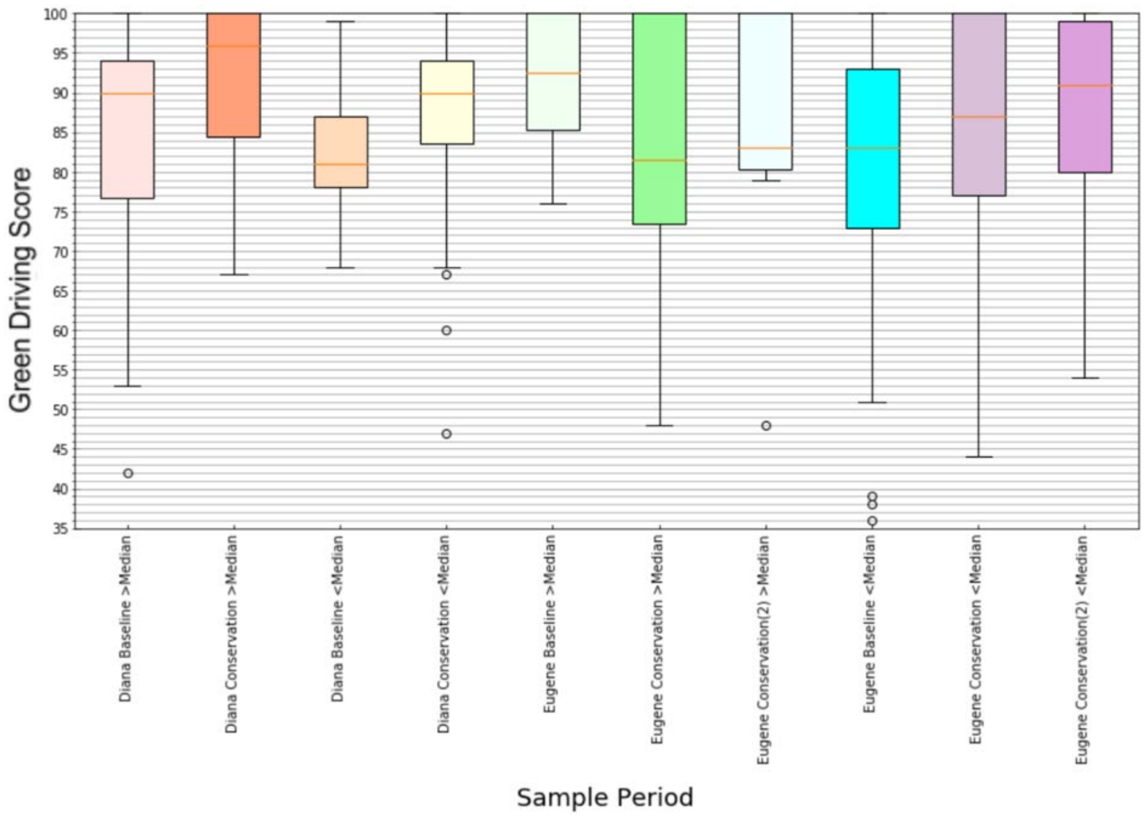

Figure 6. Results of Average Green Driving Score Based on Pro-Environmental Attitudes. Like Figure 5, this plot compares driving scores during the baseline and conservation periods, both for Diana's and for Eugene's classes; however, this plot also sub-divides students into those having pro-environmental attitudes (>median) and those not having pro-environmental attitudes (<median).

An analysis of total number of miles driven was also completed, but there were no changes seen in the data during the intervention (Figure 7). It was noted that reduction in driving was not emphasized as a method of emissions reduction in the intervention, but that driving miles per day were nevertheless still tracked for each student. As can be seen in Figure 7, weekends and holidays (e.g., Thanksgiving) show the greatest number of miles driven.

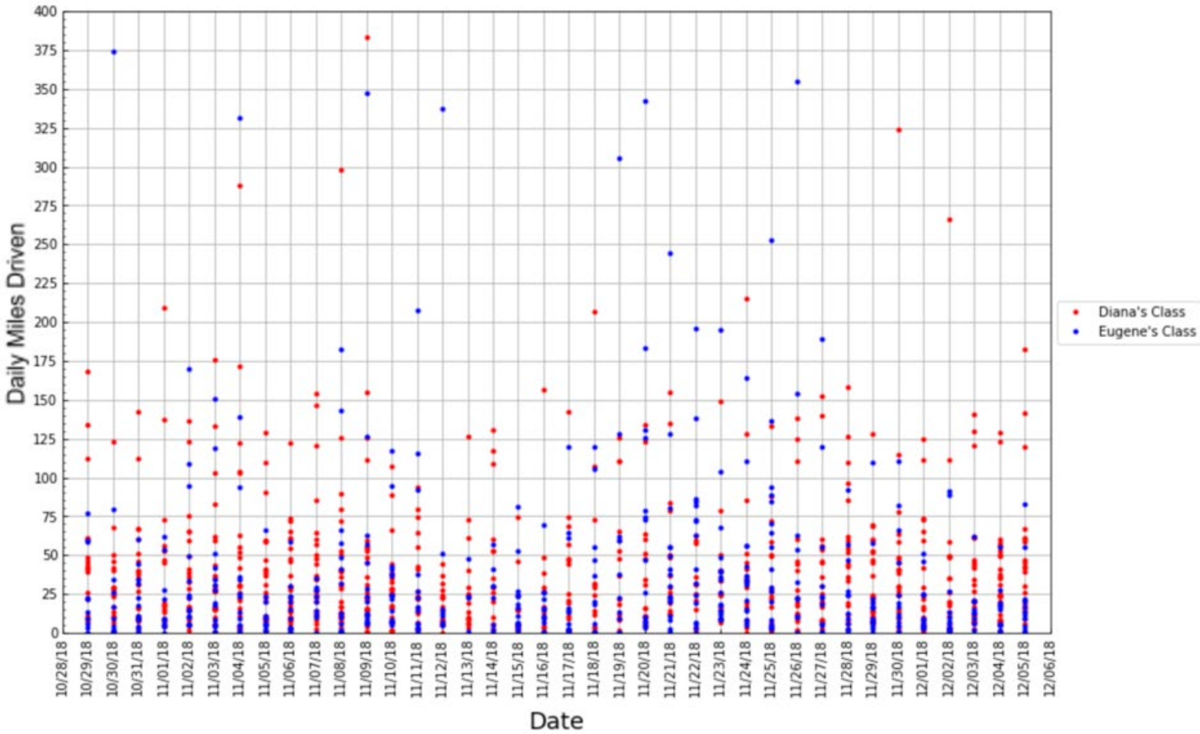

Figure 7. Total Number of Miles Driven. This graph shows the daily total distance driven for all the participating students.

UNCERTAINTIES

Student feedback on use of the application was generally positive (e.g., over 90% of Eugene's students provided favorable comments in an open-ended reflection), but noted a prominent concern: the application could not tell when students were actually the ones driving. Students were often passengers (e.g., with friends, family or ridesharing), and thus the application was often measuring the driving of someone else. Several students requested a quick and easy way to indicate that they were not driving outside of turning the app off. Also, some students took the train and light rail, which the application also measured as driving, further skewing their scores. Their movements were even recorded when they rode a bike or electric scooter. In discussions with Zendrive , their team confirmed that any time participants moved at a speed over 11mph, the application would record driving data. This was not known ahead of time, and students only became aware of this during use. Although a couple of students reported turning off the application when they were not driving, the most common comment on students' reflections of the experience related to who was actually driving. Because many students were not regular drivers, or used other forms of transportation, they may not be the best users of this technology for the purposes of data collection. Although the study can still suggest that the intervention may have demonstrated some success in improving Green Driving Scores, there is a recognition of the challenges that current phone-based applications such as these may have if transportation patterns are shifting away from single-occupancy vehicles, especially for the younger population. Although improvements in phone-based technologies are likely to address some of these challenges, a car-based device approach may also offer advantages to assessing personal driving behavior.

V. CONCLUSIONS AND RECOMMENDATIONS

The designed classroom intervention used a smartphone-based methodology to provide students with real-time feedback on their and other students' driving behavior. During an observation period, students were instructed to study their own and other students' driving patterns to better understand how driving behavior affects fuel economy and carbon emissions. Then, during a conservation period, students were encouraged using pro-environmental appeals to drive more efficiently. Student Green Driving Scores improved during the conservation period by between 2 and 5 points (out of 100). Even larger changes (between 8 and 9 points) were found in both classes when students were grouped by environmental attitudes, although it was the group that didn't initially have pro-environmental attitudes who made these larger changes. Even though additional analysis may provide new insights into the relationship between student attitudes and changes in student driving behavior, limitations exist in the fidelity of the driving data using this implementation of a phone-based tracking technology. In particular, students reported that data recorded during use of other modes of transportation (e.g., biking, electric scooters, trains and buses) also influenced their Green Driving Score, as did driving trips in which the student was not the driver. Even with these limitations, student open-ended feedback on the use of this technology was very positive. Students reported enjoying having their driving evaluated and felt that the experience taught them firsthand about how to drive more efficiently. As discussed below, students offered a number of helpful recommendations for how the smartphone application could be improved to better measure their Green Driving Score.

A number of recommendations emerged as a result of this work. As suggested by various students, improvements could be made to the smartphone technology to better measure their driving behavior. For example, notifications could provide the user with the option of turning off the tracking should they not be driving. Better GPS technologies could detect if the user was using the train or light rail, and perhaps even detect use of a bicycle or scooter. It should also be explored whether a device-based technology, attached to a single car per participant, would be a better option for data collection. The technology and social consequences of these approaches could be compared by having two groups of students using the two different technologies. The research team noted that students enjoyed using their phones and that having a driving tracker on their phone could potentially help students coach other drivers (such as their parents or friends).

A number of recommendations regarding aspects of the educational intervention are also provided here. The type of curriculum that was used to inform students about climate change and transportation was fairly standardized, but it could be made much more personal using more place-based approaches. In the future, having more student participants with a richer investigation of their environmental attitudes and behavior would also provide a better dataset for an investigation. Through a longer research project, it would also be possible to investigate whether driving behavior could be permanently changed even after the class has ended.

Given the continued improvements in smartphone- and device-based technologies to monitor driving patterns, the authors recommend additional research into the use of such technologies within classroom environments. Providing students at any age with place-based and personal data has been shown to be an effective approach to engage students, and potentially to promote pro-environmental attitudes and behavior.

APPENDIX

Global Climate Change Student Survey

Intro: Thank you for agreeing to take our survey about the METR climate change course. Please note that participation in this survey and answers to any questions are optional.

* Required

1. What is your first name? *

____

2. What is your last name? *

____

3. What is your student ID? *

____

4. What is your email address? *

____

5. What is your major?

____

6. How much do you think global warming will harm future generations?

Mark only one oval.

- Not at all
- Only a little
- A moderate amount
- A great deal
- Don’t know

7. How much do you think global warming will harm you personally?

Mark only one oval.

- Not at all
- Only a little
- A moderate amount
- A great deal
- Don't know

8. Which of the following statements comes closest to your view?

Mark only one oval.

- Global warming is not happening.
- Humans cannot reduce global warming, even if it is happening.
- Humans could reduce global warming, but people are not willing to change their behavior, so we are not going to.
- Humans could reduce global warming, but it is unclear at this point, whether we will do what is needed.
- Humans can reduce global warming, and we are going to do so successfully.

9. Rate your opinion of the following statement: The actions of a single individual will not make any difference in global warming

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

10. Rate your opinion of the following statement: New technologies can solve global warming, without individuals having to make big changes in their lives.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

11. Which comes closer to your view?

Mark only one oval.

- Most scientists think global warming is happening.
- Most scientists think global warming is not happening.
- There is a lot of disagreement among scientists about whether or not global warming is happening.
- Don’t know enough to say.

12. How much do you agree or disagree with the following statement: “I have personally experienced the effects of global warming.”

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

13. How many of your friends share your views on global warming?

Mark only one oval.

- None
- A few

14. I care about environmental issues.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

15. The Earth's temperature has warmed significantly over the last 100 years.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

16. Global warming is happening because of the way we live.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

17. If I come across information about energy and climate change, I tend to look at it.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

18. Individuals should be doing more to address global warming.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

19. I am aware of actions I can take to reduce global warming.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

20. I am interested in learning more about what to do about climate change.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

21. I am aware of how my driving behavior affects carbon emissions.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

22. I'm aware of specific actions I could take to reduce my transportation-related carbon emissions.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

23. I regularly use 'green driving' techniques to save fuel and reduce carbon emissions.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

24. I regularly look for opportunities to walk, bike or take public transit instead of driving a car.

Mark only one oval.

- Strongly agree
- Somewhat agree
- Neutral
- Somewhat disagree
- Strongly disagree

ENDNOTES

1. Pachauri, R. K. et al. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

2. Staudinger, M. D. et al. (2012). Impacts of climate change on biodiversity, ecosystems, and ecosystem services: technical input to the 2013 National Climate Assessment. United States Global Change Research Program.

3. United Nations. Framework Convention on Climate Change. (2016). Paris Agreement: Status of Ratification. Accessed at: http://unfccc.int/paris_agreement/items/9444.php

4. Plumer, B. (2017). Just how far can California possibly go on climate? New York Times, July 26. Accessed at: https://www.nytimes.com/2017/07/26/climate/california-climate-policy-cap-trade.html

5. California Air Resources Board. (2017). *California Greenhouse Gas Emission Inventory* – 2017 Edition, Accessed at:

6. https://www.arb.ca.gov/cc/inventory/data/data.htm

7. UN General Assembly, (1994). 1992 United Nations Framework Convention on Climate Change: available at: http://www.refworld.org/docid/3b00f2770.html

8. Lyons, A. C., Y. Chang and E. Scherpf. (2006). Translating financial education into behavior change for low-income populations. Financial Counseling and Planning Journal, 17(2).

9. Thomson G, J. Hoffman, S. Staniforth. (2003). Measuring the success of environmental education programs. Ottawa: Canadian Parks and Wilderness Society and Sierra Club of Canada.

10. Craig, C. A. and M. W. Allen. (2015). The impact of curriculum-based learning on environmental literacy and energy consumption with implications for policy. *Utilities Policy, 35*, 41–49.

11. Lorenzoni, I., S. Nicholson-Cole and L. Whitmarsh. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. Global Environmental Change, 17(3), 445–459.

12. Hungerford, H. R. and T. L. Volk. (1990). Changing learner behavior through environmental education. *Journal of Environmental Education, 21*(3), 8–21.

13. Kollmuss, A. and J. Agyeman. (2002). Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior?. *Environmental Education Research*, *8*(3), 239–260.

14. Bamberg, S. and G. Möser. (2007). Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. *Journal of Environmental Psychology*, *27*(1), 14–25.

15. Little, M. and E. C. Cordero. (2014). Modeling the relationship between transportation-related carbon dioxide emissions and hybrid-online courses at a large urban university. *International Journal of Sustainability in Higher Education, 15*(3), 270–279. doi: 10.1108/IJSHE-11-2012-0100.

16. Cordero, E. C., A. M. Todd and D. Abellera. (2008). Climate change education and the ecological footprint. *Bulletin of the American Meteorological Society, 89*, 865–872.

17. Todd, A. M. and E. C. Cordero. (2015). Using social media for public education and engagement on climate change: The role of media in flood management, (Geneva, World Meteorological Organization Press), Accessed at: http://www.apfm.info/publications/tools/Tool_22_The_Role_of_the_Media_in_Flood_Management.pdf

18. Walsh, E. M., D. Jenkins and E. Cordero. (2016). The promise of an energy tracker curriculum for promoting home-school connections and youth agency in climate action. Journal of Sustainability Education (11), Accessed at: http://www.jsedimensions.org/wordpress/wp-content/uploads/2016/03/WalshEtAl-11-Issue-Feb-2016-.pdf

19. Jones, C., M. and Daniel M. Kammen. (2011). Quantifying Carbon Footprint Reduction Opportunities for U.S. Households and Communities. *Environ. Sci. Technol*., 45 (9), 4088–4095.

20. Walsh, E. M., D. Jenkins and E. Cordero. (2016). The promise of an energy tracker curriculum for promoting home-school connections and youth agency in climate action. Journal of Sustainability Education (11), Accessed at: http://www.jsedimensions.org/wordpress/wp-content/uploads/2016/03/WalshEtAl-11-Issue-Feb-2016-.pdf

21. Sharma, H., S. Naik, A. Jain, R. K. Raman, R. K. Reddy and R. B. Shet. (2015). S-road assist: Road surface conditions and driving behavior analysis using smartphones. International Conference on Connected Vehicles and Expo (ICCVE), Shenzhen, 2015, 291–296. doi: 10.1109/ICCVE.2015.61

22. Yen, S. K., B. Ravani and T. A. Lasky. (2015). DOE fleet in-vehicle data acquisition system (FIDAS) technical support and testing. State of California DOE, CA16-2516

23. Murrian, M. J., et al. (2016). High-precision GPS Vehicle Tracking to Improve Safety. Data-Supported Transportation Operations and Planning Center, Technical report 115, D-STOP/2016/115. Accessed at: http://ctr.utexas.edu/wp-content/uploads/115.pdf

24. Schoenau, M. and M. Müller. (2017). What affects our urban travel behavior? A GPS-based evaluation of internal and external determinants of sustainable mobility in Stuttgart (Germany). Transportation Research Part F: Traffic Psychology and Behaviour 48, 61–73.

25. Walsh, E. M., D. Jenkins and E. Cordero. (2016). The promise of an energy tracker curriculum for promoting home-school connections and youth agency in climate action. Journal of Sustainability Education (11), Accessed at: http://www.jsedimensions.org/wordpress/wp-content/uploads/2016/03/WalshEtAl-11-Issue-Feb-2016-.pdf

BIBLIOGRAPHY

Bamberg, S. and G. Möser. (2007). Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. *Journal of Environmental Psychology*, *27*(1), 14–25.

California Air Resources Board. (2017). *California Greenhouse Gas Emission Inventory* – 2017 Edition, Accessed at: https://www.arb.ca.gov/cc/inventory/data/data.html.

Craig, C. A. and M. W. Allen. (2015). The impact of curriculum-based learning on environmental literacy and energy consumption with implications for policy. *Utilities Policy, 35*, 41–49.

Cordero, E. C., A. M. Todd and D. Abellera. (2008). Climate change education and the ecological footprint. *Bulletin of the American Meteorological Society, 89*, 865–872.

Hungerford, H. R. and T. L. Volk. (1990). Changing learner behavior through environmental education. *Journal of Environmental Education, 21*(3), 8–21.

Jones, C., M. and Daniel M. Kammen. (2011). Quantifying Carbon Footprint Reduction Opportunities for U.S. Households and Communities. *Environ. Sci. Technol*., 45 (9), 4088–4095.

Kollmuss, A. and J. Agyeman. (2002). Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior?. *Environmental Education Research*, *8*(3), 239–260.

Little, M. and E. C. Cordero. (2014). Modeling the relationship between transportation-related carbon dioxide emissions and hybrid-online courses at a large urban university. *International Journal of Sustainability in Higher Education, 15*(3), 270–279. doi: 10.1108/IJSHE-11-2012-0100.

Lorenzoni, I., S. Nicholson-Cole and L. Whitmarsh. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. Global Environmental Change, 17(3), 445–459.

Lyons, A. C., Y. Chang and E. Scherpf. (2006). Translating financial education into behavior change for low-income populations. Financial Counseling and Planning Journal, 17(2).

Melillo, J. M., T. T. Richmond and G. W. Yohe (eds.). (2014). Climate change impacts in the United States: Third National Climate Assessment. U.S. Global Change Research Program.

Murrian, M. J., et al. (2016). High-precision GPS Vehicle Tracking to Improve Safety. Data-Supported Transportation Operations and Planning Center, Technical report 115, D-STOP/2016/115. Accessed at: http://ctr.utexas.edu/wp-content/uploads/115.pdf.

Pachauri, R. K. et al. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Plumer, B. (2017). Just how far can California possibly go on climate? New York Times, July 26. Accessed at: https://www.nytimes.com/2017/07/26/climate/california-climate-policy-cap-trade.html.

Schoenau, M. and M. Müller. (2017). What affects our urban travel behavior? A GPS-based evaluation of internal and external determinants of sustainable mobility in Stuttgart (Germany). Transportation Research Part F: Traffic Psychology and Behaviour 48, 61–73.

Sharma, H., S. Naik, A. Jain, R. K. Raman, R. K. Reddy and R. B. Shet. (2015). S-road assist: Road surface conditions and driving behavior analysis using smartphones. International Conference on Connected Vehicles and Expo (ICCVE), Shenzhen, 2015, 291–296. doi: 10.1109/ICCVE.2015.61.

Staudinger, M. D. et al. (2012). Impacts of climate change on biodiversity, ecosystems, and ecosystem services: technical input to the 2013 National Climate Assessment. United States Global Change Research Program.

Thomson G, J. Hoffman, S. Staniforth. (2003). Measuring the success of environmental education programs. Ottawa: Canadian Parks and Wilderness Society and Sierra Club of Canada.

Todd, A. M. and E. C. Cordero. (2015). Using social media for public education and engagement on climate change: The role of media in flood management, (Geneva, World Meteorological Organization Press), Accessed at: http://www.apfm.info/publications/tools/Tool_22_The_Role_of_the_Media_in_Flood_Man agement.pdf.

UN General Assembly, (1994). 1992 United Nations Framework Convention on Climate Change: available at: http://www.refworld.org/docid/3b00f2770.html.

United Nations. Framework Convention on Climate Change. (2016). Paris Agreement: Status of Ratification. Accessed at: http://unfccc.int/paris_agreement/items/9444.php.

Walsh, E. M., D. Jenkins and E. Cordero. (2016). The promise of an energy tracker curriculum for promoting home-school connections and youth agency in climate action. Journal of Sustainability Education (11), Accessed at: http://www.jsedimensions.org/wordpress/wp-content/uploads/2016/03/WalshEtAl-11-Issue-Feb-2016-.pdf.

Yen, S. K., B. Ravani and T. A. Lasky. (2015). DOE fleet in-vehicle data acquisition system (FIDAS) technical support and testing. State of California DOE, CA16-2516.

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Eugene Cordero has been in the Department of Meteorology and Climate Science at SJSU for 16 years, and is also the founder of the Green Ninja initiative. Eugene's earlier research focused on the atmospheric variations associated with global climate change both in models and observations. More recently, Eugene shifted his focus towards solutions to climate change and this has yielded a collection of educational materials (i.e., curriculum, videos, games) that promote pro-environmental attitudes and behaviors in youth. Green Ninja, a university research group and a commercial enterprise in K-12 education, provides a platform where the results of research-based activities can be disseminated into schools to support teachers and their students. Eugene has built a strong team of researchers, educators, artists and practitioners who together share a vision of a more sustainable future through science and education. Eugene's educational activities have been primarily supported by NSF and NASA, but he has also secured support from local government (e.g., City of San Jose) and from private companies (e.g., World Centric).

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Diana Centeno obtained her master's degree in Meteorology from SJSU's Department of Meteorology and Climate Science. Diana's research expertise is in weather, climate and tropical cyclones. Diana has been a lecturer in the Department of Meteorology and Climate Science for the last three years, and she has been a curriculum developer and researcher for the Green Ninja initiative for the last four years. At Green Ninja, she works to support teachers with materials about climate science and climate solutions through the development of educational curriculum. Diana also works as a researcher to help analyze the role of education on carbon emissions and student attitudes and behavior.

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