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E. Cordero
San Jose State University

Anne Marie Todd
San Jose State University, annemarie.todd@sjsu.edu

D. Abellerra
Sustainability Indicators Program, Redefining Progress, Oakland, California

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CLIMATE CHANGE EDUCATION AND THE ECOLOGICAL FOOTPRINT

BY EUGENE C. CORDERO, ANNE MARIE TODD, AND DIANA ABELLERA

Action-oriented learning designed around the ecological footprint can improve university students' understanding of the connection between personal energy use and climate change.

Although recent polls¹ suggest that most Americans believe humans are indeed affecting our climate, it is unclear how well the public is educated about both the science of climate change and the connection between personal lifestyle choices and climate change mitigation. Previous studies of students and preservice teachers found that they have significant misconceptions about global warming² (e.g., Boyes and Stanistreet 1997; Christidou et al.

1997; Cordero 2002; Gowda et al. 1997; Khalid 2003; Michail et al. 2007; Uzzell 2000). For example, when asked to explain global warming, many students often discuss stratospheric ozone depletion and suggest that holes in the ozone layer enhance the greenhouse effect by allowing more solar energy to arrive at the Earth's surface (Jeffries et al. 2001).

Educators often describe such ideas as "naïve theories" or "misconceptions," and the study of how an individual constructs their own conceptual frameworks in science remains a field of continued educational research. An improved understanding of students' ideas and how they develop can lead to better instructional methods and ultimately enhance the public's understanding of science (Brody 1994; Cordero 2001; Fisher 1998a). This is certainly important in the field of climate change, where an

AFFILIATIONS: CORDERO—Department of Meteorology, San José State University, San José, California; TODD—Department of Communication Studies, San José State University, San José, California; ABELLERA—Sustainability Indicators Program, Redefining Progress, Oakland, California

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CORRESPONDING AUTHOR: Eugene C. Cordero, Department of Meteorology, San José State University, San José, CA 95192-0104

E-mail: cordero@met.sjsu.edu

The abstract for this article can be found in this issue, following the table of contents.

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¹ The polls show that 83% agree that humans are at least partially responsible for recent warming. [ABC News/Time/Stanford University Poll, March 9–14, 2006. $N=1,002$ adults nationwide, margin of error $\pm 3\%$.]

² The term "global warming" is used through the text to refer to the increase in the average temperature of the lower atmosphere over the last few decades associated with human activities, specifically the release of well-mixed greenhouse gases.

educated citizenry is required to make wise decisions regarding policies and practices aimed at reducing greenhouse gas emissions and the human impact on the Earth's resources.

Previous research confirms a need for new models of climate change education (Moser and Dilling 2004). Many educators feel that they should not only teach the science, but also engage students and encourage positive responsiveness about the environment (i.e., Cross and Price 1999; Lester et al. 2006; Mason and Santi 1998). Given the need to develop new approaches to improve awareness and understanding of climate change, we conducted a pilot study of primarily nonscience undergraduate students enrolled in introductory meteorology courses to evaluate the effectiveness of existing teaching methods and to explore new methods. The primary aim of this study is to determine the effect of action-oriented learning on climate change literacy, while yielding additional insights on student misconceptions and the effectiveness of various teaching methods. This pilot study is the initial stage of a larger project to track environmental literacy in undergraduates throughout their college education to study how, and to what extent, their knowledge of and attitudes toward climate change are affected by different learning environments. This work aims to improve climate change education and ultimately promote more sustainable practices within universities and their students.

METHODOLOGY. In the fall of 2005, over 400 college students attending San José State University participated in a study that focused on climate change science. Participants were enrolled in Meteorology 10: Weather and Climate (a lower-division general education course) and Meteorology 112: Global Climate Change (an upper-division general education course). We selected these courses because their enrollment consists primarily of nonscience majors who serve as a good benchmark for the average college student's knowledge of climate change science.

Each of the meteorology courses in this study is taught in a 15-week semester, enrolls approximately 50–60 students per course, and employs a standard lecture format. Because multiple sections are taught each semester, there are different instructors for the courses we assessed.³ Meteorology 10 focuses qualitatively on basic meteorological concepts and

covers typical introductory topics, such as radiation, general circulation, and severe weather. The course has sections on climate and climate change, including anthropogenic greenhouse gas forcing and ozone depletion. Meteorology 112 is more focused on contemporary climate change, although similar fundamentals such as radiation and the greenhouse effect are also covered. Students enrolled in Meteorology 10 tend to be first- and second-year college students, while Meteorology 112 is an upper-division course and requires at least a junior-level standing.

QUESTIONNAIRE RESULTS. We designed a questionnaire to assess student's understanding of three major areas of climate change science: 1) the causes of global warming and ozone depletion, 2) the relationship between global warming and ozone depletion, and 3) the link between energy use and greenhouse gas emissions (see <http://dx.doi.org/10.1175/2007BAMS2432.2> for a listing of the questions used in this study). The paper will focus mostly on our results in the third area. Our questionnaire consisted of 39 statements that asked for the student's response, using a five-element Likert scale (strongly agree, agree, don't know, disagree, or strongly disagree). Responses of strongly agree or agree were coded as true, and strongly disagree and disagree as false. Students were asked to complete in-class questionnaires on the first and last days of class and were then tracked by their student ID. Only students who completed both the pre- and postquestionnaires were used in this study. A *p* value from a Student's *t* test is used to indicate whether the differences between the pre- and postquestionnaires are statistically significant (where $p < 0.05$ is considered statistically significant at the 95% confidence level). We compute the *p* value from the TTEST function in Microsoft Excel, where we choose a two-tailed, two-sample equal variance test.

Student knowledge of global warming. Results from our questionnaire show that student concern about global warming is relatively high, with 80% indicating that global warming is a pressing environmental issue. Students also showed at least a rudimentary understanding of the sources and impacts of global warming. The vast majority of incoming students agreed that there is a connection between automobile and factory emissions and global warming (94% correct), and they identified CO₂ as a greenhouse gas that comes from the burning of coal and oil (83% correct). Incoming students also understood that as the Earth warms, the polar ice caps will melt and sea levels will

³ The instructors for these courses were either full-time faculty from the Department of Meteorology, or in the case of one class, an outside lecturer with a Ph.D. in atmospheric science.

rise (80% correct). These results are generally consistent across different courses and different sections of the same class.

Previously identified misconceptions in the students' understanding of global warming were also found. Students tended to confuse ozone depletion and global warming, and this confusion had only modest improvements even after a 15-week meteorology course. As shown in Fig. 1, incoming students incorrectly identify the cause of ozone depletion as CO₂ (22% correct), and the cause of the ozone hole as automobile pollution (12% correct). Students also incorrectly connect a larger ozone hole with a warmer planet (9% correct) and believe that the ozone hole will cause the ice caps to melt (18% correct). These results are consistent with previous studies of K-12 and college students in the United States, United Kingdom, and Australia (Christidou et al. 1997; Cordero 2002; Fisher 1998b; Rye et al. 1997) and confirm that these misconceptions persist in today's students. We also note that although statistically significant improvements ($p < 0.05$) between the pre- and postquestionnaire occur in all but one question, the percentage of correct answers is still not very impressive. Previous research has also described the challenges that exist in altering student misconceptions (Brody 1994; Fisher 1998b), and our findings imply that further teaching innovations are needed in our general education courses to change student ideas.

Ecological footprint learning activity. The ecological footprint (EF) (see sidebar) is an analysis that estimates the resources required to sustain a human population and compares this to the Earth's regenerative capacity. The EF computes an area of land needed to sustain a population and its activities, using inputs to the calculation, including carbon emissions from food choices, transportation modes, and a number of other factors. The carbon emissions tend to be the greatest component of an individual's, as well as a nation's, EF contribution. In this way, calculations of EF can be related to greenhouse gas emissions and indirectly to global warming.

Because previous questionnaires showed that students' understanding of the connection be-

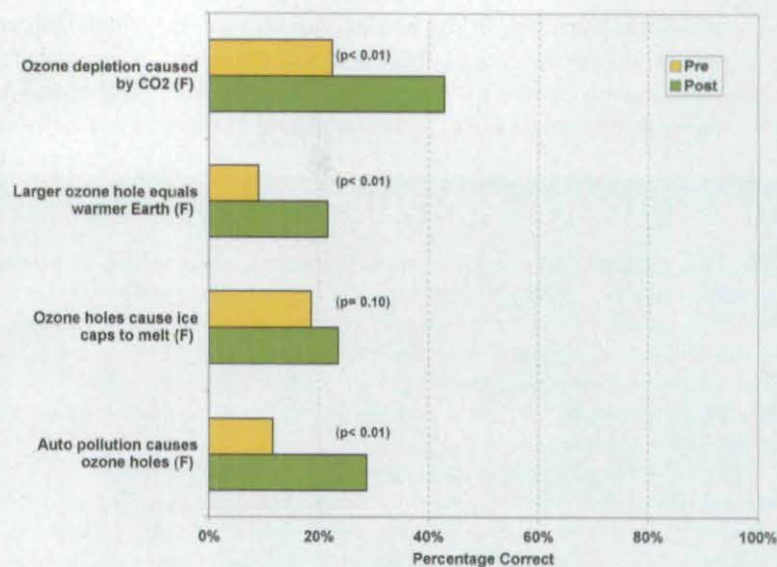


FIG. 1. Student responses ($n = 470$) to the statements regarding the connection between global warming and the ozone hole. Results from questionnaires given at the beginning of the semesters (prequestionnaire and end of the semester (postquestionnaire) from both sets of meteorology general education classes are shown. A shorthand version of the question followed by the correct answer indicated by "(T)" or "(F)" is given on the left, and the p value is given on the right.

tween energy use and global warming is poor, we designed a learning activity (<http://dx.doi.org/10.1175/2007BAMS2432.2> for details) to encourage students to explore the connection between personal energy use and their EF. The activity was given to approximately half the Meteorology 112 students ($n = 123$) and included the following components: a) students completed the online EF quiz (see sidebar); b) students used the "Take Action" section to determine how they might reduce their overall EF by 30%; and c) students answered questions (requiring paragraph responses) about how their various activities contribute to their EF. The activity was worth 10% of the course grade and students were given 2 weeks to complete their work. There was neither in-class discussion of the EF, nor feedback given on the activity until after the final questionnaire was completed. Hereafter, Meteorology 112 students who were given the EF learning activity are referred to as the "Yes EF" group while Meteorology 112 students who were not given the activity are called the "No EF" group.

We analyzed results from the two groups of Meteorology 112 students ($n = 241$) to evaluate the impact of the EF activity on the students' understanding of global warming. The greatest variations between these two groups of students were found in the questions regarding the connection between personal energy use (e.g., consumption, electricity use, and a vegetarian diet)

and global warming. In the preclass questionnaire, the average percentage of correct responses to these questions was between 14% and 39%. These results, like previous studies (e.g., Andersson and Wallin

2000; Hillman et al. 1996) suggest the following misconception: causes of global warming include only visible and local pollution (i.e., automobile exhaust and factory emissions), and exclude energy associated

THE ECOLOGICAL FOOTPRINT

The EF is a scientifically reviewed tool for measuring human impact on the environment through calculating the amount of land needed to provide all of the resources and absorb all of the wastes of any given population (Wackernagel et al. 2002). Although the calculator is best applied at a global, national, and regional level, individuals may determine their footprints through an online quiz (available online at www.earthday.net/footprint/index_reset.asp). Accessed by 6 million people each year from over 45 countries, the EF quiz prompts users to answer a series of multiple-choice questions about their daily lifestyles. Examples of the questions are shown in Table SBI, and illustrate the connection between personal activities and environmental resources.

From a pedagogical point of view, two features of the EF quiz are especially interesting. First, after individuals complete the quiz, their results are displayed on a screen as shown below. The total footprint is broken down into different components (food, mobility, shelter, goods/services), and an estimate of the amount of resources is presented in acres and in "number of planets required if everybody lived like you." The use of the quantity "number of planets" instead of just acres of land puts the global ramifications of individual actions into perspective and also allows for comparisons with other countries. The second pedagogically significant part of the EF quiz is the "Take action" section, where participants can see how changes to various actions would affect their total footprint (see Fig. SBI). Note: A new EF quiz has been released (www.myfootprint.org) that upgrades the version used in our study. While it offers more accurate calculations and updated information, it lacks the 'Take action' functionality. The authors recommend (www.footprintnetwork.org/calculator) as a calculator that enables the user to modify their actions and immediately see the result.

TABLE SBI. Sample questions given in ecological footprint quiz are shown.

1. How often do you eat animal based products (beef, pork, chicken, fish, eggs, dairy products)?

- Never (vegan)
- Infrequently (no meat, and eggs/dairy a few times a week; strict vegetarian)
- Occasionally (no meat or occasional meat, but eggs/dairy almost daily)
- Often (meat once or twice a week)
- Very often (meat daily)
- Almost always (meat and eggs/dairy in almost every meal)

2. How much of the food that you eat is processed, packaged, and not locally grown (from more than 200 miles away)?

- Most of the food I eat is processed, packaged, and from far away
- Three-quarters
- One-half
- One-quarter
- Very little; most of the food I eat is unprocessed, unpackaged and locally grown

6. Which housing type best describes your home?

- Free-standing house without running water
- Free-standing house with running water
- Multistory apartment building
- Row house or building with 2–4 housing units
- Green-design residence

12. Approximately how many hours do you spend flying each year?

- 100 h
- 25 h
- 10 h
- 3 h
- Never fly

with electricity generation and energy associated with the production of products and food.

In the Yes EF group, the percentage of correctly answered questions, as shown in Fig. 2, significantly

improved by the end of the semester and was also significantly higher than in the No EF group. In all cases, the changes are statistically significant at the 99% confidence level ($p < 0.01$). In the statement regarding energy-saving light bulbs (*Energy-saving light bulbs can save money, but have no effect on global warming*), 82% of the Yes EF group answered correctly while only 29% in the No EF group did so. In responses to the related statement (*Electric automobiles do not contribute to global warming*), similar improvements were observed, although the changes in the Yes EF group were not as large. These results indicate that the activity helped students dispel the previously identified misconception that electricity is somehow “clean” and not connected to global warming.

Responding to the statement “*Buying bottled water instead of drinking water from a faucet contributes to global warming*” only 21% of all Meteorology 112 students answered correctly. In the Yes EF student group, this improved to a 53% correct response, while the No EF group showed no statistically significant improvement at the 95% level. For the statement, “*Eating a vegetarian diet can reduce global warming*,” the initial correct response by all Meteorology 112 students was 14%, while the Yes EF group improved to 80% and the No EF group to 24%. For both questions, the EF activity appears to help students connect products and personal actions with energy use and global warming. This is especially true for the connection with food; students appear to discover the role meat consumption has on global warming (see, e.g., Eshel and Martin 2006).

The improvements in the students’ understanding of one aspect of global warming appears to be directly connected to the EF learning activity. A question about home energy use on the EF and in the activity encourages students to explore the connection between electricity and the EF. Also, the EF quiz asks two questions about the type of food one buys and the activity again asks the student to explain why food choices alter their EF. In both cases, we see dramatic improvements in student responses. Based on both of these results and student comments, we believe the personal connection this activity establishes helped students learn. By asking students to use the online calculator to reduce their footprint by 30% in a realistic manner allows students to apply their understanding and evaluate how it impacts their lives. Using trial and error, most students find that food choices were the easiest change they could make to reduce their EF. This may explain why the largest improvement in student responses was in reference to the questions on a vegetarian diet. The relatively

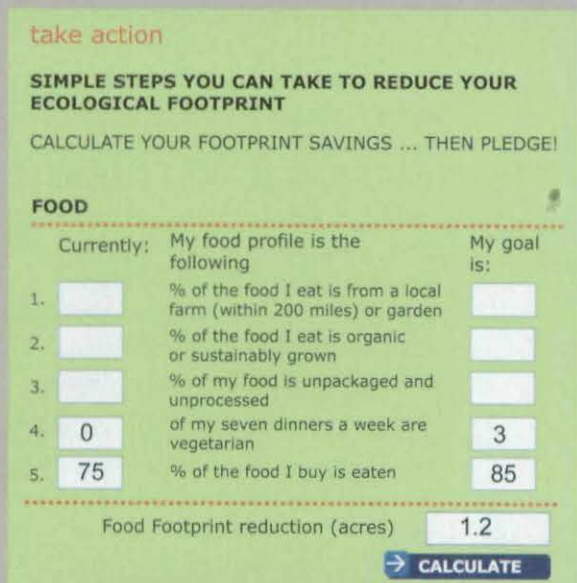
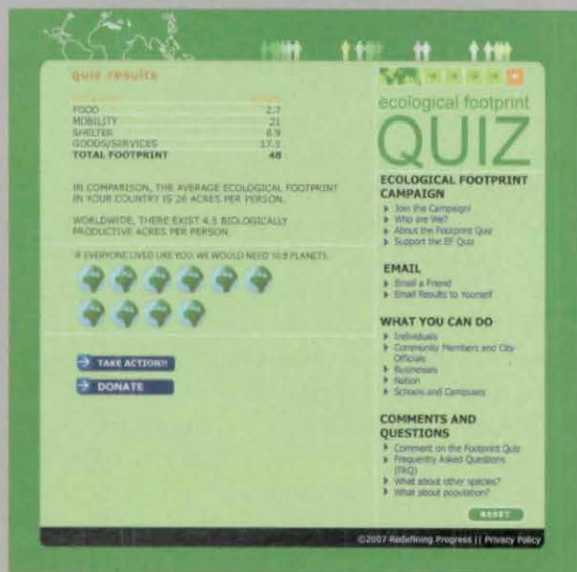


Fig. SBI. Two sample screens from the ecological footprint quiz given to a selection of students (online at www.earthday.net/footprint/index_reset.asp): (top) the results after completion of the footprint quiz, and (bottom) the “Take action” section, where students can quantify how particular actions can modify their ecological footprint. Note that the ‘Take action’ section is no longer available in the English version of this calculator.

smaller improvements in answers about bottled water may have also been predicted, because the only EF question focused on consumption—*Compared to people in our neighborhood, how much waste do you generate; much less; about the same; much more*—is not as strongly illustrated. In grading the written response to the question of why waste affects your EF, many students mentioned recycling but did not describe the direct connection between consumption and energy.

Comments by students who completed the activity revealed that the EF activity influenced how they perceived the connection between their lifestyle and global warming. Of these students, over 50% responded that they were “surprised” or “shocked” at their results. Other studies have identified this “I didn’t know I have this much impact” refrain in students (Devine-Wright et al. 2004; McMillan et al. 2004) and adults (Uzzell 2000). In general, students were also surprised at how relatively easy it was to reduce their EF, and many said they would consider changing from a diet of primarily meat and/or processed foods to a diet with more local fruits and vegetables. This may actually be quite important because it offers students an achievable method toward reducing their EF. Research shows that guilt is generally not a good motivator for personal change (Moser and Dilling 2004), and this may also be true in learning. While

this analysis does indicate that EF activity improves students’ knowledge of the environmental impacts of their actions, it does not indicate whether these educational experiences will be retained over time.⁴ However, it does suggest that a learning activity designed around personal action may be a good motivator for learning.

DISCUSSION AND CONCLUSIONS. Climate change today is no longer the exclusive domain of scientific experts; it calls for action from all citizens (Bäckstrand 2003). Higher education, in particular, has an important role to play in educating students about climate change, and connecting it to the variety of social dimensions, including access to food, drinkable water, and sustainable energy (Rees 2003). A scientifically literate population can make better decisions about what and how they purchase, consume, dispose, and invest (Lester et al. 2006). Previous studies show that introductory university-level environmental studies classes can improve students’ environmental literacy (McMillan et al. 2004). However, educators have found limited success in getting students to apply environmental knowledge to their own lives, and curricula that utilize environmental connections have been weak (e.g., Devine-Wright et al. 2004; McBean and Hengeveld 2000).

The results from our questionnaire show that significant misconceptions persist among university students concerning climate change. The confusion is likely enhanced via various factors, including how the media portrays global warming and how these topics are covered in K–12 classes (e.g., Dove 1996; Gowda et al. 1997; Groves and Pugh 1999; Moser and Dilling 2004). Our results dem-

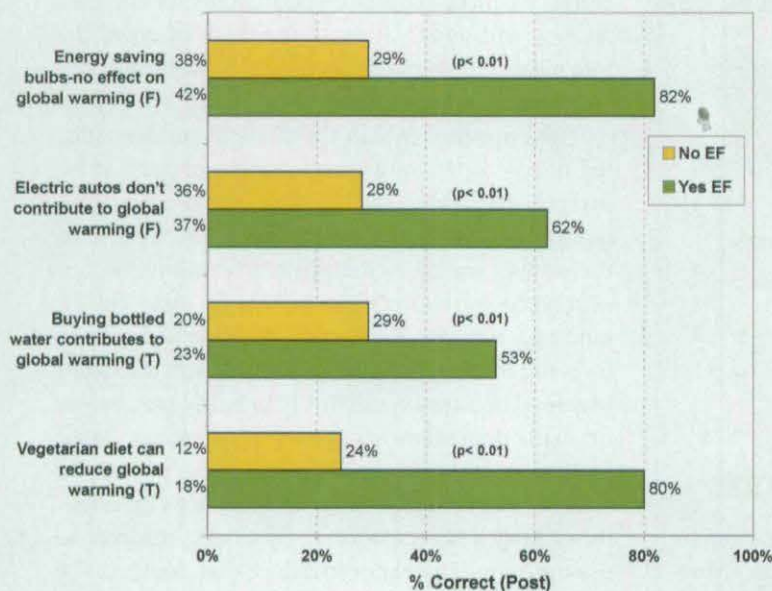


FIG. 2. The percentage of correct student responses from the end of semester questionnaire ($n = 241$) for Meteorology 112 classes with and without the ecological footprint activity. The percentage of correct student responses at the beginning of the semester (prequestionnaire) is also given to the left of the bar. A shorthand version of the question followed by the correct answer indicated by “(T)” or “(F)” is given on the left, and the p value is given on the right.

⁴ In a 2006 project conducted by Redefining Progress, over 300 K–12 teachers across California were trained on integrating the EF into their curriculum. Feedback from participants showed that teachers developed new perspectives in teaching history/social studies and found the EF offered a key means for critical thinking and student reflection. Whether the EF activity can promote a deeper and longer-lasting understanding of other aspects of climate change science is at present unclear, but these preliminary results show the inherent promise of establishing a personal connection between the students and the science.

onstrate that some of these misconceptions do not change even after a 15-week course in weather and climate. Other studies have found that even highly educated adults harbor significant misconceptions about basic elements in climate science (e.g., Sterman and Sweeney 2007), illustrating that it often takes specific curriculum design to alter student ideas.

The main conclusion of our study is that effective climate change education should emphasize the personal connection between the student, energy, and climate change using active learning methods. Our results demonstrate that students who completed a relatively simple action-oriented learning activity designed around their ecological footprint significantly improved their understanding of the connection between personal energy use and global warming. Critics of conventional environmental education propose that curriculum focused solely on science without personal and social connections may not be the most effective educational model for moving toward social change (Uzzell 1999). Our results suggest that the EF activity described here is an example of an effective curriculum design that provides a pathway for enhancing student understanding and possibly altering student behavior in a manner that promotes deeper learning.

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THE LIFE CYCLES OF EXTRATROPICAL CYCLONES



Edited by Melvyn A. Shapiro and Sigbjørn Grønås

Containing expanded versions of the invited papers presented at the International Symposium on the Life Cycles of Extratropical Cyclones, held in Bergen, Norway, 27 June–1 July 1994, this monograph will be of interest to historians of meteorology, researchers, and forecasters. The symposium coincided with the 75th anniversary of the introduction of Jack Bjerknes's frontal-cyclone model presented in his seminal article, "On the Structure of Moving Cyclones." The monograph's content ranges from a historical overview of extratropical cyclone research and forecasting from the early eighteenth century into the mid-twentieth century, to a presentations and reviews of contemporary research on the theory, observations, analysis, diagnosis, and prediction of extratropical cyclones. The material is appropriate for teaching courses in advanced undergraduate and graduate meteorology.

The Life Cycles of Extratropical Cyclones is available for \$75 list/\$55 members. Prices include shipping and handling. Please send prepaid orders to Order Department, American Meteorological Society, 45 Beacon St., Boston, MA 02108-3693 or call (617) 227-2426 ext. 686. Visa, MasterCard, or American Express accepted.

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