Examining the impacts of a graduate course on sustainable development using ecological footprint analysis

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Abstract

Purpose – The purpose of this study is to use ecological footprint analysis (EFA) in an interdisciplinary graduate level course on sustainable development to better how education can facilitate learning and transform the perceptions and behavior of class participants.

Design/methodology/approach – This study uses an untreated control group research design with a pre-test and post-test to measure and explain the change in the EF of students enrolled in a graduate course on sustainable development taught at Texas A&M University in the spring of 2004. We uses the study test of means and multivariate regression analysis to make statistical conclusions about the degree to which education on sustainability affects the way students act and also to identify the major factors driving this behavioral change.

Findings – Results indicate that that graduate-level education can significantly increase students' sustainable behavior as measured by their ecological footprints (EF) and that specific socioeconomic and proximity-based variables contribute to this observed phenomenon.

Practical implications – This study provides insights into the effectiveness of teaching sustainable development courses at institutions of higher education by examining the change in specific EF components and identifying variables which help predict the change in EFs over the course of the semester.

Originality/value – This study uses an empirically-driven, quantitative approach to understand the degree to which graduate-level coursework on the topic of sustainable development transforms the perceptions and behavior of class participants.

Keywords Sustainable development, Graduates, Problem based learning, Higher education

Paper type Research paper

Introduction

Institutions of higher learning are increasingly being viewed as important vehicles for fostering sustainable behavior and contributing to the agenda of sustainable approaches to development worldwide. Over the last 30 years, the issue of education in achieving

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sustainable practices has become more prominent in both the international and national arena. The seeds for incorporating aspects of sustainability into higher education were first planted with the signing of *The Stockholm Declaration* in 1972 (Calder and Clugston, 2003). However, it was not until *The Talloires Declaration* in 1990 that university administrators signed an explicit statement of commitment to support sustainability efforts in institutions of higher learning (Wright, 2002). This ten-point voluntary action plan urged universities to "engage in education, research, policy formation and information ... to move toward a sustainable future" (ULSF, 1990). As of 2001, approximately 280 universities in over 40 countries have signed the declaration.

The discussion on critical dimensions of sustainability in higher education[1] has continued through the signing of multiple international declarations, the implementation of national programs, and specific initiatives within universities (Clugston and Calder, 1999; Wright, 2003). While all of these initiatives have their own nuances, one theme is prominent: institutions of higher education have a responsibility to develop curriculum, teach, and train students on the principles of sustainability. And, universities should impart the knowledge and skills that will enable graduates to create the changes required to achieve a more sustainable society.

While some of the broad principles of sustainability and higher education have been defined, systematic knowledge of the impact of existing initiatives and ways to effectively incorporate sustainability into university curricula is limited due to a lack of empirical research on the subject. The descriptive and advocacy-oriented research pervading the literature has recently received considerable criticism from environmental education scholars (Palmer, 1999; Fien, 2002). For example, Fien (2002) notes the majority of studies on sustainability in higher education lack rigorous research designs in that they fail to report on data collection procedures, data analysis, and issues of validity. The author suggests that the use of empirical-analytical approaches such as *quasi-experimental* pre- and post-test designs may be one of several research paradigms to advance the state of knowledge on sustainability and higher education. Similarly, Corcoran *et al.* (2004) argue case study research[2] lacking a rigorous research design and discussion of methodology has failed to live up to its potential for improving the field of sustainability. Based on an analysis of 54 journal articles on sustainability in higher education, the authors found that case studies (the predominant method of research on the topic) rarely included information on research methods and instead relied on stories of successes to support their argument.

This study uses an evidence-based approach to examine the degree to which graduate-level coursework on the topic of sustainable development transforms the perceptions and behavior of class participants. Specifically, we use ecological footprint analysis (EFA) in an interdisciplinary graduate level course on sustainable development taught at Texas A&M University to answer the following research questions:

RQ1. Does graduate education on sustainable approaches to development significantly impact sustainable behavior patterns?

RQ2. What are the major factors contributing to a change in individual levels of sustainability?

A pretest-posttest design with a nonequivalent control group enable us to make statistical conclusions about the degree to which education on sustainability affects the way students act and also to identify socioeconomic and proximity variables driving this behavioral change. The course encouraged authentic inquiry by employing a problem-based learning (PBL) approach where students actively participated in solving complex real-world problems associated with sustainability.

The following section examines two areas of literature forming the conceptual basis of our study:

(1) the role of PBL in teaching issues associated with sustainability; and
(2) the use of EFA to measure and explain individual levels of sustainability.

Next, we describe the research methods used in the study, including sample selection, concept measurement, and data analysis. Statistical results based on paired tests of means and ordinary least squares (OLS) regression analysis identify the degree to which course content and PBL techniques changes the size of ecological footprints (EFs) and explain the variation in footprint scores at the post-test phase of analysis. Finally, we discuss the implications of our findings in terms of improving educational programs on sustainability and achieving more sustainable levels of activity at the societal level.

The role of PBL in teaching issues associated with sustainability

While there is no consensus on how best to actually teach sustainability at the university level, one approach called PBL has received recent attention in the environmental education literature (Jucker, 2002; Steinemann, 2003; Warburton, 2003). PBL emerged as a response to criticism that traditional classroom environments do not provide essential contextual features that enable students to understand and apply information (Schmidt, 1993). In these contexts, students frequently are not active agents in the learning process but are instead passive receptors of knowledge provided by an imposed educational structure. In contrast, PBL is grounded in the notion that learning occurs when students are given problems and situations that represent genuine complexity (Brown *et al.*, 1989). Since authentic tasks mirror reality, they are thought to help students become aware of the relevance of what they are learning. As a result, PBL prepares students to solve real world, interdisciplinary problems associated with sustainability once they leave the classroom environment and become working professionals. Directing students to work through actual sustainable development scenarios (e.g. green building, site and community designs, simulated negotiation, etc.) builds their capacity to address the complex interaction of human decisions and the biophysical environment.

A central premise of PBL is linking theoretical knowledge to practical application through the use of collaborative groups in which students are responsible for deciding what is to be learned. A greater level of responsibility, competency, and learning results when an authentic problem is shared by a team of students and the goal of the course is to solve the problem collectively (Peterson, 1997; Friedman and Deek, 2002). The rationale for instructional strategies that encourage cooperation between learners is that such strategies more closely approximate the real world than traditional didactic approaches (Coppola, 1996a, b; Cockrell *et al.*, 2000). In real life, sustainable approaches to development often require interdisciplinary teams working together and the cross-fertilization of knowledge.

Research on PBL has indicated that collaborative groups are associated with higher levels of student learning and critical reasoning capabilities (Gabbert *et al.*, 1986). According to Walton and Mathews (1989), PBL provides constant, iterative practice of a logical, analytical, and scientific approach to problem solving that yields effective reasoning skills. Foremost, PBL promotes the idea that nothing is ever learned to finality, that interdisciplinary learning coincides with solving the complex interrelated problems of sustainability, that there exists too much for any one person to learn, and that tasks need to be shared among students.

A major instructional element of authentic learning and PBL is the use of collaborative groups to explore, analyze, and solve problems presented in case form (Cockrell *et al.*, 2000). Three main characteristics of case studies make them an ideal strategy to facilitate authentic learning. First, a case is based on a real situation or event forcing students to think through a problem they may encounter in the work place. Second, the case study is developed through careful research and study. Third, and most important, a case provides learning opportunities at various levels for those involved in the construction of the case as well as for those who may interact with the case (Wallace, 2001). In general, a well-crafted case anticipates scenarios that a learner might eventually face in situations that do not allow time for careful deliberation (Coppola, 1996a). Such situations are common in the field of ecologically sustainable planning and development.

Ecological footprint analysis as an indicator of sustainability

EFA is one method that may help evaluate the effectiveness of teaching sustainability at institutions of higher education. This technique offers a quantitative measure of sustainability that can be systematically tracked and compared across individuals, households, institutions, and geographic areas. Rees and Wackernagel first introduced the EF concept in an effort to convert these broad principles into a measurable indicator of whether population demands remain within the confines of the earth's natural capital stocks (Wackernagel *et al.*, 1999b). An EF is measured as the total area of productive land and water required to continuously produce all resources consumed and to assimilate all wastes produced by a defined population in a specific location (Rees and Wackernagel, 1996).

The usefulness of EFA is that it aggregates and converts typically complex resource use patterns into a single number (Costanza, 2000). EF calculations are based on two basic assumptions: first, most consumption and much of the waste people generate can be accounted for; and second, the biologically productive areas appropriated for these consumption patterns and the assimilation of waste can be calculated (Wackernagel *et al.*, 1999a). Consumption categories include: food, housing, transportation, consumer goods, services, and wastes. An EF is usually expressed in global acres (or hectares). Each global acre corresponds to one acre of biologically productive area based on the earth's average productivity.

EFA has been applied at various geographic scales, including global/national, municipal/institutional (Barrett and Scott, 2003; Flint, 2001), and individual levels (Crompton *et al.*, 2002). At the household scale, individual impact is often assessed through direct accounting or simplified questionnaires (Wackernagel and Yount, 2000). Simmons and Chambers (1998) devised an EF tool for households called "EcoCal", an easy-to-use computer-based questionnaire comprised of 45 questions. The authors used the tool to measure the EF of 42 households in the UK and found that the average household EF is almost 5 or 1.7 hectares per occupant. The EF ranged from less than 0.5 hectares per household to several hundred hectares. A high EF score generally resulted from large families with energy-inefficient homes taking long-haul holidays abroad coupled with "high impact" purchases (Simmons and Chambers, 1998). Crompton *et al.* (2002) introduced the EF concept into an undergraduate course at the Open University, UK as a learning tool. Using the "EcoCal" program, students were required to calculate their EF and then consider how changes in their lifestyles could decrease their overall impact on natural resources. The average EF from 692-student samples was only 3.34 hectare per household, or 1.33 hectare per person. Households without children (under 16 years) had a higher EF per person than households with children; rural households had a higher average transport EF than urban residents. On average, transportation and energy consumption accounted for nearly three-quarters of the total household per capita EF.

Modeling the ecological footprint and environmental behavior

While numerous studies have measured EF at different sociopolitical scales, few have sought to explain the variation in footprint scores. Venetoulis (2001) examined carbon prints for cities in Los Angeles County, California. The results of this study indicate a positive relationship between footprints and per capita income, environmental values, and land use density. This research showed that higher levels of income correspond with larger EFs, but have a negligible effect when analyzed along with environmental values. This particular study also found that more compact cities where residents live closer to places of work have smaller overall footprints. In their study of university students, Crompton *et al.* (2002) found that households without children (under 16 years) had a higher EF than households with children and that rural households had a higher average transport EF than urbanites who tend to reside closer to work. These results reinforce the conclusions of many other studies (Brower and Leon, 1999; Venetoulis, 2001): that transportation mode, distance to work, and related levels of energy consumption are the key factors contributing to the size of an EF.

Most recently, Ryu and Brody (2004) found that socioeconomic characteristics are the most significant predictors of household EFs in Dallas County, Texas. Using multivariate regression analysis, the authors found that older, non-married, highly educated male respondents with high household incomes have significantly larger EFs. The authors, however, note that socioeconomic variables alone are insufficient in predicting average personal footprint of Dallas County (less than 30 percent of the variance) and that other variables such as proximity to work, land use density, and existing environmental perceptions may also have a significant effect on per capita EFs.

Owing to the paucity of empirical studies explaining the variation in EFs, we also reviewed the related literature on environmental behavior to gain insight on the specification of our conceptual model. Multiple studies in the field of environmental psychology have relied upon socioeconomic and demographic variables, such as age, education, income, political orientation, and occupation to explain broad-scale environmental perceptions and behavioral patterns (Buttell, 1987). Generally, these studies conclude that young women with high levels of income and education and with liberal political views are the most likely to consider environmental protection a priority. For example, Van Liere and Dunlap (1980), Jones and Dunlap (1992), and Scott and Willets (1994) all found the same results: young, highly educated, liberal-minded individuals demonstrate greater recognition of and concern for environmental problems. Other studies focusing on the role of socioeconomic factors find evidence that younger age (Fransson and Garling, 1999; Honnold, 1981; Nord *et al.*, 1998) higher income levels (Scott and Willets, 1994), and higher levels of education (Guagano and Markee, 1995; Howell and Laska, 1992; Raudsepp, 2001) are significant drivers of environmental concern and consequent activity. Finally, Raudsepp (2001) found women were significantly more likely than men to be concerned with environmental problems.

Methods

Sample selection and treatment

Our study uses an untreated control group research design with a pre-test and post-test to measure and explain the change in the EF of students enrolled in a graduate course on sustainable development taught at Texas A&M University in the spring of 2004. The treatment or study group consisted of 22 graduate students enrolled in the sustainable development course. This class was comprised of both masters and doctoral level students from one of the following three programs within the College of Architecture: Urban Planning, Architecture, and Land Development. The control group consisted of 28 students enrolled in a general graduate level market analysis for development course (with no emphasis on sustainability) taught within the college.

The design and content of the sustainability course was based on the PBL approach described above. The course covered a broad range of topics related to sustainable planning and development. Readings and discussions were organized by sociopolitical scale as opposed to media (air, water, waste, etc.) or subject matter (ecology, economics, social equity, etc.). Substantive class sessions were grouped into the following seven study units: global/biosphere, national, institutional/organizations, community, site, building, and household/individual. Within each unit a range of sub-topics was explored including social equity, economic development, ecology of place, urban form, and sustainable enterprise (see Figure 1 for course framework). The approach of the course was problem-based where students had the opportunity to apply the principles of sustainability to realistic problems, settings, and solutions. In-class group exercises included: designing a sustainable community, addressing the adverse environmental impacts from a subdivision development, and developing a concept design for a sustainable house based on specific site requirements. Place-based case studies were assigned as part of required readings and subsequently discussed in class. In general, the content of the course was meant to help prepare students to address the interdisciplinary, complex problems associated with sustainability in their work and everyday lives.

The objectives of the sustainable development course were thus to:

- understand the principles of sustainable planning and development at and between a variety of scales and settings;
- critically examine the challenges and opportunities to build, plan for, and direct sustainable communities;

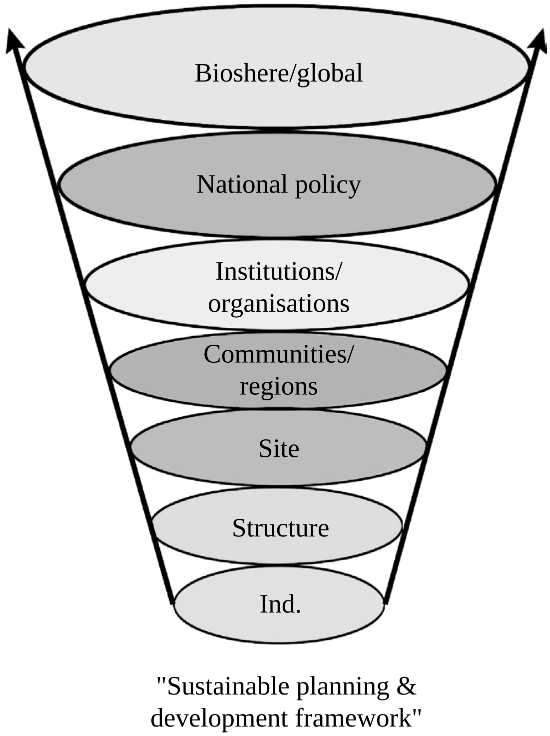

Figure 1.
Sustainable development course outline

- apply the principles of sustainable planning and development to real-world problem domains, working alone and in groups; and
- develop individual and collective student expertise on a topic related to sustainability to enhance professional development and increase effectiveness in the workplace after graduation.

The course was reading intensive and discussion-based. Students were expected to apply their own knowledge and specializations to solving specific sustainable planning and development problems from a variety of perspectives. Several problem papers were assigned asking students to apply the concepts presented throughout the course to real-world planning and development situations. A final project required students, either working alone or in groups, to identify, analyze, and present to the class a place-based sustainability problem of their choice.

Concept measurement

Dependent variable: post-test ecological footprint score. We calculated each respondent's post-test EF by administering the EF Quiz originally designed by the nongovernmental organization, Redefining Progress (Appendix 2, Table AII). The survey, consisting of 16 questions, was given to each group at the beginning and end of the academic semester. Consumption activities for each survey question were weighted by a "footprint factor" calculated by the amount of energy and land needed to support the given activity. Footprint factors were pre-calculated by redefining progress according to national levels of productivity. Multiplying each respondent's level of activity by its corresponding footprint factor yielded an equivalent impact in terms of acres of land/sea that can be compared across all nations (for more detail on individual EF calculation, refer to Merkel (2003)).

A composite EF score was calculated by aggregating four separate components: food, mobility, housing, and goods and services. The food component summed up land and marine areas that sequester CO_2 from the energy expended to grow, process, and transport food. Survey questions included the types of food respondents regularly eat and where this food is produced. The mobility component was based on impacts from walking, cycling, driving cars, and flying. Respondents were asked to provide information on their mobility habits including the mode, distance, and relative energy efficiency of their daily travel or commute. The housing footprint component was based on yard area, energy, and materials for constructing buildings. Specific questions included the size and type of shelter, and the number of inhabitants. Finally, the goods and services component considered consumer behavior patterns such as use of appliances, electronics, computers, and communications equipment. Specific questions also obtain information about utility use including water, sewer, and trash disposal services. The four footprint components were combined into a single variable. A Cronbach's α of 0.7 indicates that the composite variable is reliable and has good internal consistency[3]. The composite EF was measured for each respondent and averaged over each group, creating a continuous scale.

Independent variables. We calculated independent variables using information obtained through the EF surveys (Appendix 2, Table AII and Appendix 1, Table AI). Pre-test EF scores were measured using the same procedures for post-test scores described above and entered into the model as a predictor variable. Group was measured as a dichotomous variable where 1 is the study group and 0 is the control group. Gender was also a dichotomous variable where 1 is male and 0 is a female respondent. Age and income, as reported by survey respondents, were measured as continuous variables. In measuring students' environmental awareness, we utilized selected questions on the degree to which humans are impacting the environment initially used by Van Liere and Dunlap (1980). Seven separate questions regarding the degree to which humans are impacting the environment on a scale from 1 to 4 were combined into a single variable. Cronbach's α for the final scale is 0.86. Respondents were asked to indicate whether they strongly agree, agree, disagree, strongly disagree, or have no opinion on each of the questions. Responses were summed and ranged from 1 (strongly agreeing that humans are abusing the natural environment) to 28 (strongly disagreeing that humans are abusing the environment). Finally, distance to work was measured as a self-reported approximate one-direction distance in miles from respondents' place to the campus or each of their work places.

Data analysis

The data were analyzed in two phases. First, paired tests of means assessed the change in footprint scores between the pre-test and the post-test for both the study and control groups. Second, multiple regression analysis on the combined sample (control and study groups) identified the most influential factors contributing to EF change between pre-test and post-test. We analyzed five separate OLS regression models, one for each component and a composite footprint score. Several statistical tests for reliability were conducted to ensure the OLS estimators were best linear unbiased estimates (BLUE). Tests for model specification, multicollinearity, autocorrelation, and heteroskedasticity revealed no violation of regression assumptions.

Results

Based on the initial survey (pre-test), the per capita EF of the class on sustainable development was 19.5 acres. Of the class composite score, 26 percent came from the food component, 14 percent from mobility, 25 percent from shelter, and 35 percent from goods and services. The control group had a very similar pre-test EF score of 20.6 acres per person. The component scores were also quite similar, where 26 percent of the composite EF was from the food component, 14 percent from mobility, 26 percent from shelter, and 34 percent from goods and services.

Comparing the means of the pre-test and post-test scores for both the study and control groups provides an initial indication of the impact of education on individual levels of sustainability (Table I). Subsequent to the treatment, the sustainable development class' per capita composite EF decreased significantly to 16.8 acres ($p < 0.05$), while the control group's EF significantly increased to 23.1 acres. While food and shelter EF components did not change significantly during the three-month study period, the study group showed marked reductions in both mobility and goods/services components ($p < 0.1$). For example, the mobility EF component decreased from 2.8 to 1.9 acres and the goods/services component dropped from 6.6 to 5.5 acres per person subsequent to treatment (Brody and Ryu, 2005).

The second phase of analysis used OLS regression analysis to identify some of the major factors contributing to the change in EF scores over time. Table II reports the results of regression analysis explaining the impact of graduate course on students' post-test composite footprint score. As expected the pre-test EF score is the most significant predictor of the post-test score ($p < 0.01$). Those with large existing

Variable	Pre-test (mean)	Post-test (mean)	t-value	p-value
Composite footprint				
EF				
Study ($N = 22$)	19.5	16.8	2.39	0.026
Control ($N = 28$)	20.6	23.1	−2.06	0.049
Component footprint				
Food				
Study	5.1	4.8	1.42	0.170
Control	5.3	5.1	1.13	0.269
Mobility				
Study	2.8	1.9	2.03	0.055
Control	2.8	3.4	−1.59	0.123
Shelter				
Study	5.0	5.0	−0.07	0.949
Control	5.4	6.2	−1.62	0.117
Goods/services				
Study	6.6	5.5	1.98	0.061
Control	7.1	8.3	−2.13	0.042

Table I. The paired t-tests for study and control groups

Dependent	Unstandardized coefficient	Standard error	Standardized coefficients	t-value	Significance
Composite EF					
Group	−5.287	1.641	−0.273	−3.221	0.003
Age	0.307	0.162	0.166	1.901	0.065
Gender	−0.123	1.870	−0.006	−0.066	0.948
HH income	0.067	0.029	0.199	2.256	0.030
Environ. value	1.550	1.826	0.079	0.849	0.402
Pre-test EF	0.576	0.125	0.536	4.618	0.000
Dist. to univ.	0.108	0.054	0.224	1.996	0.054
(Constant)	−2.376	6.105		−0.389	0.699

Notes: $N = 44$, $F(7, 36) = 17.145$, prob. $> F = 0.000$, adj. $R^2 = 0.724$

Table II. Explaining "Composite EF"

footprints are more likely to have large footprints at the end of the semester. However, students in the study group have a negative effect on post-test score, indicating that the semester-long course on sustainable development significantly reduced the size of the per capita EF ($p < 0.01$) while controlling for other variables. This finding confirms the results of a one-way between-groups analysis of covariance controlling for pre-test EF scores using the same data conducted by Brody and Ryu (2005), which provided an initial indication of the positive impact of education on individual levels of sustainability.

The household income level ($p < 0.05$) and age of students ($p < 0.1$) also are significant predictors of post-test composite scores. On average, older, wealthier students are associated with larger EFs and less sustainable behavior patterns (particularly considering the relatively small sample size and lack of statistical power). We also found that those living farther from the university and traveling longer distances to campus have significantly larger footprints, most likely from using more resources for transportation. In contrast, gender and existing environmental values have no statistical bearing on post-test EF scores.

Tables III-VI report regression results for the four EF sub-components. The pre-test score is the only variable consistently significant in all of the models. That is, an

Dependent	Unstandardized coefficient	Standard error	Standardized coefficients	t-value	Significance
Food EF					
Group	−0.096	0.239	−0.048	−0.402	0.690
Age	0.002	0.025	0.009	0.067	0.947
Gender	−0.024	0.260	−0.011	−0.091	0.928
HH income	0.004	0.004	0.107	0.872	0.389
Environ. value	−0.019	0.274	−0.009	−0.070	0.945
Pre-test EF	0.685	0.133	0.706	5.141	0.000
Dist. to univ.	0.003	0.006	0.050	0.391	0.698
(Constant)	1.378	1.079		1.278	0.210

Notes: $N = 44$, $F(7, 36) = 6.324$, prob. $> F = 0.000$, adj. $R^2 = 0.464$

Table III. Explaining "Food EF"

Table IV.
Explaining "Mobility EF"

Dependent	Unstandardized coefficient	Standard error	Standardized coefficients	*t*-value	Significance
Mobility EF					
Group	−1.227	0.563	−0.229	−2.181	0.036
Age	−0.028	0.056	−0.055	−0.500	0.620
Gender	−0.092	0.636	−0.017	−0.145	0.885
HH income	0.022	0.010	0.2423	2.215	0.033
Environ. value	0.809	0.616	0.149	1.313	0.198
Pre-test EF	0.466	0.120	0.476	3.889	0.000
Dist. to univ.	0.032	0.016	0.242	1.995	0.054
(Constant)	0.316	2.025		0.156	0.877

Notes: $N = 44$, $F(7, 36) = 9.432$, prob. $> F = 0.000$, adj. $R^2 = 0.579$

Table V.
Explaining "Shelter EF"

Dependent	Unstandardized coefficient	Standard error	Standardized coefficients	*t*-value	Significance
LN shelter EF					
Group	−0.057	0.112	−0.054	−0.508	0.615
Age	−0.005	0.011	−0.051	−0.465	0.644
Gender	−0.096	0.124	−0.087	−0.773	0.444
HH income	0.004	0.002	0.209	1.898	0.066
Environ. value	−0.035	0.122	−0.033	−0.285	0.777
Pre-test EF	0.159	0.026	0.812	6.059	0.000
Dist. to univ.	−0.002	0.003	−0.075	−0.570	0.572
(Constant)	0.990	0.401		2.470	0.018

Notes: $N = 44$, $F(7, 36) = 9.125$, prob. $> F = 0.000$, adj. $R^2 = 0.569$

Table VI.
Explaining "Goods and Services EF"

Dependent	Unstandardized coefficient	Standard error	Standardized coefficients	*t*-value	Significance
Goods/service EF					
Group	−2.394	0.805	−0.282	−2.974	0.005
Age	0.087	0.079	0.108	1.104	0.277
Gender	−0.047	0.905	−0.005	−0.051	0.959
HH income	0.030	0.014	0.204	2.081	0.045
Environ. value	0.819	0.897	0.095	0.914	0.367
Pre-test EF	0.477	0.130	0.455	3.668	0.001
Dist. to univ.	0.061	0.026	0.287	2.364	0.024
(Constant)	−0.159	2.927		−0.054	0.957

Notes: $N = 44$, $F(7, 36) = 12.677$, prob. $> F = 0.000$, adj. $R^2 = 0.655$

existing footprint score is the most reliable predictor of footprint size at the end of the semester. Aside from the pre-test scores, no other predictor variable is significant in the model explaining the food EF (Table III). This is the weakest fitting model explaining EF subcomponents as noted by its comparatively lower adjusted r-squared value of 0.464. The treatment group significantly reduces its EF in the model explaining the mobility component (Table IV) indicating the effectiveness of the graduate course in changing student behaviors related to transport. Household income is also an important predictor of post-test mobility EF scores where, on average, higher income levels translate into larger EFs. As expected, proximity to the university has a statistically significant impact on increasing EF scores for the mobility component. In the model explaining the shelter EF component, only the pre-test scores ($p < 0.05$) and income ($p < 0.1$) predictor variables are statistically significant. In this case, the treatment group did not significantly reduce its EF scores associated with shelter by the end of the course. Finally, the model explaining the goods and services post-test EF has the strongest predictive power of all components (Table V). The treatment group shows the most significant reduction in its EF compared to the other components. In addition to the pre-test scores, income levels and distance to the university are also significantly positive predictors of post-test EF scores associated with goods and services.

Conclusions

This study provides insights into the effectiveness of teaching sustainable development courses at institutions of higher education. Results indicate that graduate level education can significantly increase sustainable behavior as measured by their EF. Findings support the effectiveness of PBL techniques in teaching the principles of sustainable development and the ability of a single course to change student consumptive patterns in a period of only three months. A significant decrease in the per capita EF for the treatment group is particularly encouraging given the fact that student footprints were already well below the national average of approximately 24 acres per person (most likely due to a general lack the financial resources to maintain large EFs). Educational programs may be even more effective in reducing the EF for those at or above the US average because there will be more room for improvement or greater opportunity to make easy gains.

Examining the change in specific EF components also provides insights into how higher education can alter individual consumption patterns to more sustainable levels. For example, the mobility and goods and services components of the treatment group both decreased by approximately a full acre. We believe these components represent “low hanging fruit” in terms of improving sustainable behavior, particularly during a short-time period. It is relatively easy to alter one’s mode of transportation and service-oriented or luxury item purchases compared to modifying housing type or diet. Changing living arrangements would take more time given leasing commitments and the general lack of housing options available for students. Reducing food EFs is also more problematic given the characteristics of the commercialized food market in College Station, Texas. Students rely on a limited number of large grocery stores where food selection emphasizes animal-based products and items not grown locally, which require more energy in producing food for processing, packaging, and storage.

Identifying variables which help predict the change in EFs over the course of the semester also provides direction for educators teaching sustainable approaches to development. On average, a student taking PBL course on sustainable development is more likely to reduce his or her EF by the end of the semester than a student not taking the course. However, several factors actually contribute to an increase in footprint size. First, older students have significantly larger EFs presumably because they have accumulated more resources over time and are more set in their ways in terms of their daily consumption patterns. Thus, an educator may want to consider the average age of the class, among other factors, before designing a sustainable development curriculum. Second, students with higher household incomes also have larger footprints due to a greater financial capacity to live in larger residences, drive larger automobiles (which are usually less fuel efficient), and purchase more luxury goods and services. This finding may have implications for an educator teaching the principles of sustainability in a private school where incomes tend to be higher versus a rural public institution where students generally have less financial resources. Third, the farther away a student lives from the university, the larger his or her EF because more transportation-related resources are needed for commuting purposes. While not a commuter school, Texas A&M University is the largest campus by land area in the US students frequently rely on automobiles to reach campus or travel from one building to another. Proximity variables may not be as important for courses taught at a school located in a more urbanized community with more public transportation alternatives and a more contained central campus where students can walk to class. Finally, the fact that existing environmental values are not significantly correlated with post-test EF scores is an important result in understanding how higher education can foster sustainable behavioral patterns. This study finds that a student's core values and perceptions on the environment are not contingent on their willingness to reduce the size of their EF. That is, higher education can change behavior without having to alter or contend with core values that are already solidified by the time a student enters a graduate program.

While this study provides empirical evidence supporting the effectiveness of sustainability in higher education, it should be considered only an initial step in understanding how graduate coursework can foster more sustainable patterns of behavior. Further *quasi-experimental* research is needed on several fronts. First, we surveyed only one study and control group during a single semester. Multiple classes surveyed at several points in time would increase the statistical validity and power of the findings. Second, our survey was limited to a single university in Texas, reducing our ability to externalize the results to other regions. Multiple universities in different areas of the country would help account for regional variations in student body and consumption alternatives. Third, our results are vulnerable to the threat of interaction between selection and history (sometimes called local history). Events other than the treatment could have affected the experimental group but not the control group, contributing to the observed decrease in EF scores. More effort is needed to account for history threats such as campus or departmental events or the subjects of other courses the students took during the same semester. Finally, this study only measures EFs at the beginning and ends of a semester and can make no conclusions whether education-induced behavioral changes are enduring. Additional research is needed to determine if graduate courses can produce permanent alterations in lifestyle or if they have only a short-lived effect.

Notes

1. For a more detailed description on the history of sustainability in higher education, see Wright (2002).
2. For a more detailed discussion on this topic, see *Environmental Education Research*, Special Issue, Volume 10, Number 1: Case-Study Research in Environmental Education.
3. The four footprint components were combined into a single variable. A Cronbach's α of 0.7 indicates that the composite variable is reliable and has good internal consistency.

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(The Appendix follows overleaf.)

Appendix 1

Table AI.
Correlation matrix

	ef02	*food02*	*mobl02*	*shlt02*	*goods02*	*ef01*
ef02	1					
food02	0.444**	1				
mobl02	0.732**	0.341**	1			
shlt02	0.798**	0.200**	0.321**	1		
goods02	0.975**	0.370**	0.719**	0.796**	1	
ef01	0.758**	0.354**	0.576**	0.557**	0.741**	1
food01	0.378**	0.739**	0.329**	0.199**	0.330**	0.380**
mobl01	0.555**	0.235**	0.657**	0.246**	0.542**	0.858**
shlt01	0.767**	0.212**	0.351**	0.765**	0.740**	0.851**
goods01	0.707**	0.294**	0.520**	0.517**	0.708**	0.986**
group	−0.335**	−0.142**	−0.291**	−0.196**	−0.347**	−0.065**
gender	0.215**	−0.007**	0.167**	0.151**	0.177**	0.233**
age	0.180**	−0.124**	−0.043**	0.100**	0.120**	0.032**
hhincm	0.390**	0.264**	0.380**	0.303**	0.348**	0.198**
ecovalue	0.370**	0.387**	0.421**	0.132**	0.364**	0.367**
dis_work	0.607**	0.307**	0.499**	0.382**	0.608**	0.645**

	food01	*mobl01*	*shlt01*	*goods01*	*group*	*gender*	*age*
ef02							
food02							
mobl02							
shlt02							
goods02							
ef01							
food01	1						
mobl01	0.206**	1					
shlt01	0.219**	0.511**	1				
goods01	0.297**	0.844**	0.832**	1			
group	−0.081**	0.003**	−0.095**	−0.062**	1		
gender	0.086**	0.219**	0.237**	0.191**	0.055**	1	
age	−0.163**	−0.052**	0.208**	0.012**	0.144**	0.270**	1
hhincm	0.169**	0.194**	0.197**	0.139**	−0.278**	0.227**	0.205**
ecovalue	0.476**	0.282**	0.233**	0.350**	−0.138**	0.247**	−0.045**
dis_work	0.375**	0.476**	0.594**	0.630**	0.051**	0.023**	0.128**

	hhincm	*ecovalue*	*dis_work*
ef02			
food02			
mobl02			
shlt02			
goods02			
ef01			
food01			
mobl01			
shlt01			
goods01			
group			
gender			
age			
hhincm	1		
ecovalue	0.198**	1	
dis_work	−0.003**	0.294**	1

Notes: ** = < 0.01; * = < 0.05. Terminologies: ef02 – lobal acres (posttest EF score); food02 – global acres (posttest food EF score); mobl02 – global acres (posttest mobility EF score); shlt02 – log of global acres (posttest shelter EF score); goods02 – global acres (posttest goods and services EF score); ef01 – pre-test composite EF score; food01 – pre-test food EF score; mobl01 – pre-test mobility EF score; shlt01 – pre-test shelter EF score; goods01 – pre-test goods and services EF score; group – study (= 1)/control (= 0); gender – reported gender; age – reported age in years; hhincm – reported household annual income, in 1K$; ecovalue, degree of awareness on the level of human impacts on the natural environment; dis-work, reported neatest distance to university, in miles

Appendix 2

Name	Type	Measurement	Scale	Source	Mean	SD
Composite EF	Dependent	Global acres (post-test EF score)	Continuous	Survey	20.3	9.3
Food EF	Dependent	Global acres (post-test food EF score)	Continuous	Survey	5.0	1.0
Mobility EF	Dependent	Global acres (posttest mobility EF score)	Continuous	Survey	2.7	2.5
LN shelter EF	Dependent	Log of global acres (posttest shelter EF score)	Continuous	Survey	1.6	0.5
Goods EF	Dependent	Global acres (posttest goods EF score)	Continuous	Survey	7.1	4.1
Group	Independent	Study(= 1)/control (= 0)	Dichotomous 1-0	Survey		
Age	Independent	Reported age in years	Continuous	Survey	26.4	5.3
Gender	Independent	Reported gender	Dichotomous	Survey		
HH income	Independent	Reported household annual income, in 1K$	Continuous	Survey	23.9	29.3
Environ. value	Independent	Degree of awareness on the level of human impacts on the natural environment	Dichotomous 1-4	Survey	2.1	0.5
Pre EF	Independent	Pre-test composite EF score	Continuous	Survey	20.1	8.8
Pre food	Independent	Pre-test food EF score	Continuous	Survey	5.2	1.1
Pre mobility	Independent	Pre-test mobility EF score	Continuous	Survey	2.8	2.7
Pre shelter	Independent	Pre-test shelter EF score	Continuous	Survey	5.2	2.6
Pre goods/services	Independent	Pre-test goods and services EF score	Continuous	Survey	6.9	4.0
Distance to univ.	Independent	Reported neatest distance to university, in miles	Continuous	Survey	7.9	19.7

Table AII.
Conceptual measurement

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