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Effects of childhood setting and interaction with nature on academic performance in introductory college-level courses in the environmental sciences

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Abstract

This study explored the relationships between student background and academic performance in college introductory environmental science (ES) courses at a large U.S. research university with the premise that this analysis may inform teaching practices, curricula, and efforts to increase retention. We surveyed over 700 students across eleven introductory ES courses and used multiple linear mixed-effects regressions to model the data. We found that students who grew up in rural settings or who had frequent childhood interactions with natural environments earned higher grades, on average, than students from urban settings or with fewer childhood interactions with natural environments. Our results indicate that students reporting frequent childhood interactions with forests, for example, were projected to earn grades up to 1.5 letter grades higher in these courses than students with no such interactions. In addition, students with frequent childhood interactions with nature were likelier to report that such interactions helped them in their ES course, suggesting that these students may recognize the value of these experiences. Greater interest in the subject matter also correlated with higher ES course grades, whereas amount of prior ES coursework did not. We discuss the possible implications of these correlations for ES academic performance and educational practice.

Keywords

environmental science; introductory course; student background; rural; interest

Introduction

Over the next decade, the American workforce is predicted to face a deficit of one million college graduates in the fields of science, technology, engineering, and mathematics (STEM; Olson and Riordan 2012). Consequently, the U.S. higher education system has looked to increase student retention in STEM programs, where currently less than 40% of students

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who enter college intending to major in a STEM field ultimately complete such a degree (Olson and Riordan 2012). One of the strongest predictors of student persistence is performance during the first year of STEM coursework (Chen and Soldner 2013; Crisp, Nora, and Taggart 2009; Ost 2010; Rask 2010). Students who perform poorly in introductory STEM courses are more likely to switch to non-STEM majors or drop out of college compared to students who succeed in such courses (Chen and Soldner 2013; Ost 2010). These trends highlight the need for a better understanding of why students struggle in introductory courses and what might be done to adjust teaching practices to promote persistence.

Poor student performance in introductory STEM courses appears to be the result of many factors. Contributing variables include personal factors such as mental and physical health, familial and social networks, and financial support (DeBerard, Spielmans, and Julka 2004; Pritchard and Wilson 2003); motivational factors such as self-efficacy, interest in school, and time spent studying (Chemers, Hu, and Garcia 2001; Kuh et al. 2008; Robbins et al. 2004); and institutional factors such as academic support, class size, and the teaching methods used in introductory (gateway) courses (Cromley, Perez, and Kaplan 2016; Freeman et al. 2014). In particular, many studies have focused on how student background impacts performance in introductory STEM courses, which is especially relevant considering the diversification of the college student population over the past several decades (Broido 2004; Deil-Amen 2011; Pryor et al. 2007). However, most of these studies examine the effects of macro-scale factors, such as gender, race, ethnicity, high school performance, and test scores (Ackerman, Kanfer, and Calderwood 2013; Crisp, Nora, and Taggart 2009; Kim 2015; Kokkelenberg and Sinha 2010). While those factors are unquestionably important, many other aspects of student background likely influence performance in introductory STEM courses, perhaps with some being particularly or exclusively relevant to specific STEM disciplines.

In this study, we identified specific aspects of student background that influence academic performance in introductory college environmental science (ES) courses. We focused on ES because prior, small-scale studies have suggested that performance and retention in ES programs are influenced by aspects of student background specifically relevant to ES coursework, such as whether students grew up on a farm (Ball 2001; Dyer, Breja, and Wittler 2002; Greene and Byler 2004; Mousel, Moser, and Schacht 2006). Using a survey, we expanded on this work by measuring aspects of student background potentially linked to course performance that may be specific to the ES discipline (i.e., childhood residence setting and amount of pre-college interaction with natural environments), as well as those that may impact course performance more broadly across STEM disciplines (i.e., interest in the subject and the amount of relevant prior coursework).

Childhood residence setting and interaction with nature

Although many aspects of student background influence academic performance in college courses, the relative importance of specific factors likely varies across disciplines. For example, we might expect frequent childhood interactions with natural environments and growing up in a rural setting to improve performance in ES college courses, but not in disciplines outside the natural sciences. Indeed, experience with natural environments has

already been shown to affect performance and retention in agricultural science programs. Agriculture programs, some of the oldest ES-related programs in the U.S. higher education system, have seen noticeable changes in the backgrounds of their student populations over the past several decades. In the 1970s and 1980s, enrollment in agricultural science programs rapidly declined (Dyer and Osborne 1994; Manderscheid 1988), and as enrollment in these programs rebounded in the 1990s, they observed an influx of students from more urban settings (Diechert 2004; Dyer, Lacey, and Osborne 1996; Williams 2007). This demographic shift spurred agricultural educators to characterize the relationship between student demographic changes and academic performance and program retention. The resulting studies reported that students who grew up in more urban settings or who lacked childhood agricultural experiences were likelier to underperform their peers in agricultural courses or leave agricultural programs altogether (Ball 2001; Dyer, Breja, and Wittler 2002; Greene and Byler 2004; Mousel, Moser, and Schacht 2006).

While these studies found that childhood residence and agricultural experience contributed to academic success in agricultural courses, it is unknown whether similar trends hold across different ES programs. Here, we expanded on this previous work by testing whether growing up in a more rural setting and having more frequent interactions with natural environments during childhood improve academic performance in introductory college ES courses.

Student interest and prior coursework

We also examined the relationship between ES course performance and two aspects of student background shown to influence performance broadly across STEM disciplines: student interest in the subject and prior coursework in the subject. Student interest has been shown to lead to beneficial learning behaviors and outcomes, including increased attention, note-taking, recall, and depth of learning while reading text on a topic (Schiefele and Krapp 1996). Interest also leads students to work harder on and spend more time with learning material, and engage in deep learning (Renninger, Hidi, and Krapp 2014). Thus, it is not surprising that student interest is associated with greater academic success across grade levels and disciplines (Ferrell, Phillips, and Barbera 2016; Harlow, Harrison, and Meyertholen 2014; Schiefele, Krapp, and Winteler 1992), including college agriculture courses (Hoover 2017).

Learners of all ages construct and organize new concepts around prior understanding and preconceptions. Thus, students who lack foundational knowledge or who hold misconceptions about a topic tend to struggle when learning new material (Mestre 2001; Council 2000; Piaget 1978; Piaget and Cook 1952). Educators often assume that prior coursework provides students with the necessary foundational knowledge for success in future courses. In support of this view, taking prior courses in a subject is often correlated with higher grades in future courses across STEM disciplines (Harlow, Harrison, and Meyertholen 2014; Loehr et al. 2012; Sadler and Tai 2001; Schwartz et al. 2009). Within the context of ES, one agricultural program reported that students who had completed at least one high school agriculture course were more likely to finish their college agriculture degree (Dyer, Breja, and Wittler 2002). Therefore, there may be a connection, either direct or

indirect, between performance in college ES courses and previous exposure to the foundational concepts of those courses.

In the present study, we recognized that students may thus learn foundational ES concepts formally via prior ES courses in school, as well as informally via childhood interactions with nature that were unstructured or facilitated by mentors other than teachers. We believe this distinction is important because learning is often context-specific, such that knowledge gained informally outside of the classroom might not be as easily transferred to concepts formally learned within a classroom (Carragher, Carragher, and Schliemann 1985; Lave 1988; Council 2000). Here, we tested the prediction that a greater amount of ES education, whether formal (via prior coursework) or informal (via childhood interactions with nature), would improve academic performance in introductory college ES courses.

Student self-assessment

In addition to the relationships between student background and performance in ES courses, we also assessed whether students recognized that their prior experience with the natural world might have influenced their performance in these courses. Though prior research has shown that natural environments can serve as learning settings for children and contribute to their cognitive development (Cooper 2015; Louv 2008; Wells 2000), we asked whether college students would see prior childhood experiences in nature as valuable to their current academic success. Prior work has also indicated that student background influences self-efficacy, or a student's confidence in their own academic abilities, and that a strong self-efficacy is associated with higher grades (Kim 2014; Michaelides 2008). Thus, there is reason to predict that students who believe that their experiences will help them in a course are more likely to succeed in that course.

Study questions

We asked two questions in this study: 1) What aspects of student background best correlate with academic performance in introductory college ES courses? and 2) Can students accurately identify aspects of their background that helped them perform better in such courses? To answer the first question, we focused on the four aspects of student background summarized above: a) Childhood residence setting (i.e., rural, suburban, or urban); b) Frequency of childhood interactions with natural environments; c) Interest in ES topics; and d) Amount of prior ES coursework. We predicted that higher grades in ES courses would be associated with students who grew up in more rural settings, had more frequent childhood interactions with natural environments, reported greater interest in ES topics, and had taken a greater amount of prior ES courses.

To address our second research question, we first determined whether students' self-assessed understanding of a foundational ES concept aligned with their academic performance in their ES courses. However, students may have acquired their foundational understanding of ES concepts from various sources. For example, some students may have learned about ES concepts formally in prior ES courses, while others may have learned about them informally by interacting with nature as a child. In addition to looking at the relationship between these aspects of background and final course grades, we also asked students to report whether they

thought their childhood interactions with natural environments helped them perform better in their course. By corroborating their self-reported understanding of ES concepts with their performance levels, and by asking whether their interactions with nature aided their performance, we felt we could begin to understand whether students can accurately assess how their background influences their performance in college ES courses.

By identifying relationships between student background and performance in introductory college ES courses, we hoped to uncover relationships that could guide future work assessing methods of improving academic performance in these courses and retention in ES programs more broadly. Additionally, we hoped to encourage other researchers to identify aspects of student background that influence academic performance in ways that are specific to other STEM disciplines.

Methods

Survey methodology

To answer our research questions, we administered a survey to eleven introductory ES courses at a large research University in the Midwestern United States and correlated survey responses to final grades. We administered the survey to the courses in person (ten courses) or online (one course) during the Spring and Fall 2012 semesters (Table 1). We chose to look at lower-level courses because performance in introductory courses is a strong predictor of retention in STEM programs (Chen and Soldner 2013; Crisp, Nora, and Taggart 2009; Ost 2010; Rask 2010). The University is in a mid-sized urban area and reported in 2012 that it enrolled 27,097 undergraduates, of which 48% identified as male, 78% as Caucasian, 6% as Asian American, 6% as International, 4% as Hispanic American, 3% as African American, and 3% identified as Native American, Native Hawaiian, or unknown. We designed the survey in consultation with the University's Survey Center. The surveyed courses were distributed across several environmentally focused departments, including coursework in Environmental Studies, Forest and Wildlife Ecology, Botany, Atmospheric and Oceanic Sciences, Soil Science, and Agronomy. All surveyed courses were primarily lecture-based and taught by professors, teaching assistants, or both, with students being graded via a combination of quizzes and exams, writing assignments, attendance, and participation via clicker questions or in-class or online discussions. Only 2 of the 11 courses included field trips, and the median course size was 157 students (Table 1).

The survey consisted of 23 questions, including demographic questions (e.g., gender and academic rank) and questions related to a student's interest in ES-related topics, amount of prior ES coursework, childhood residence setting, and frequency of childhood interactions with components of natural environments (Table 2). We administered 783 surveys, and, at the end of the semester, instructors supplied us with final letter grades for all students (i.e., 4.0 = A, 3.5 = AB, 3.0 = B, etc.), which we linked to completed surveys via coded identifiers. We obtained IRB approval for this research and followed all associated guidelines. Correcting for differences in the distributions of grades between courses, the final grades of students who responded to our survey were approximately 0.43 letter grades higher on average than those who did not ($p < 0.001$). As such, our data likely reflect a

slightly higher-performing sub-population of ES students enrolled in introductory ES courses at this University.

Data management and preparation

We compiled our data in Excel and analyzed them in R (R Core Team 2017), making figures using *ggplot2* (Wickham 2016). To answer our first question—which aspects of student background best correlate with academic performance in introductory college ES courses—we constructed a multiple linear mixed-effects regression model with survey responses about background as fixed factors and grades as the dependent variable. The first step we took towards constructing this model was to numerically code question responses (Table 2); for this regression, we selected only those questions related to student background for further consideration. For example, question 15 (*Understanding*, Table 2) was not considered because it was a self-assessment question rather than a background question.

Then, we accounted for possible autocorrelation between question pairs so as to not confound the interpretation of the coefficient estimates the model would produce. We first generated a correlation matrix for all pairs of questions that could both be coded numerically (R function: *hetcor*; R package: *polycor*; Fox 2016; Table 3). From this, three sets of correlations were deemed problematic: Questions 9 (*Childhood Residence*) and 5 (*HS Setting*; Pearson's $r = 0.89$); Questions 23 (*Environment Interest*) and 3 (*Career*; Pearson's $r = 0.78$); and Questions 8 (*Parent Setting*) and 10 through 14 (*Forest, Soil, Farm, Plants, Garden*; Pearson's r values with *Parent Setting* all > 0.50). Following this analysis, we chose the *Childhood Residence*, *Career*, and *Parent Setting* questions to include in the regression model to the exclusion of their correlates, for which we assumed they would serve as logical proxies.

In the case of the *Career* versus *Environment Interest* pairing, we chose the *Career* question as a proxy for interest for two reasons. First, while 778 respondents answered the *Career* question, only 637 respondents answered the *Environment Interest* question because it was added to the survey later in the study (Table 2). As such, use of the *Career* question as a proxy for interest in ES topics allowed us to retain 141 otherwise usable responses in our regression. Second, and more important, we felt the *Career* question represented a better measure of *strong* interest in ES topics than did the *Environment Interest* question. A comparison of the responses to the two questions (Fig. 1) lends support to this assumption. All students who reported “no interest” in the natural environment also reported they did not plan to pursue an ES-related career, whereas 44% of “very interested” students planned to pursue such a career. Moreover, the proportion of students who planned to or were unsure if they planned to pursue an ES-related career also increased with interest in the natural environment.

In the case of the *Parent Setting* question versus the five questions about frequency of interactions with components of natural environments (questions 10 through 14), we chose to include the former question in our regression because we assumed its strong correlation with each of the other five questions would make it a good proxy for interactions with natural environments more generally. However, when we found that *Parent Setting* was a non-significant predictor of student grades in our regression model (see Results), we tested

the validity of this assumption *post priori* using a Principle Components Analysis (PCA; R function: *prcomp*; R Core Team 2017). We included the responses to *Parent Setting*, the responses to questions 10 through 14, and median-centered grades (see below) in this PCA. The first two components together explained 63.9% of the variance (49.3% and 14.5%, respectively). Component 2 was loaded negatively with the grade data (−0.947) and also loaded with the *Farm* (0.195), *Forest* (−0.169), and *Parent Setting* (0.192) data, whereas the first component was fairly evenly loaded with all the included survey question data (loadings between −0.305 and −0.448). A biplot (Fig. 2) of the first two components revealed that responses to the *Parent Setting* question were least parallel with student grades, whereas responses to the *Forest* question were the most parallel with grades—and, by extension, the most likely to be correlated with them. We tested this conclusion by substituting the *Forest* question for the *Parent Setting* question *post priori* to generate an alternative regression model (see below), which we also present in the Results.

As expected, grade distributions differed between courses (Table 1). To minimize the extent to which these differences affected the results of our regressions, we median-centered and standardized the raw grade data by subtracting the corresponding median course grade (including the grades of non-respondents) from each student's raw grade and then dividing each result by the corresponding inter-quartile range (IQR) for grades in each student's respective course. These data can be interpreted as follows: A student with a median-centered grade of 0 received the median grade in his or her course, whereas students who received median-centered grades of 1 and −1 received grades one IQR above or below their course's median grade, respectively. This correction minimized differences in teaching style, course culture, grade distribution, and course format to the extent possible. Prior to the correction, course median grades ranged from 3.0 (B) to 3.5 (AB), and grade IQRs ranged from 1.0 to 2.0 (one to two letter grades; Table 1).

Statistical analyses

In our multiple linear mixed-effects regression model, we included responses to focal survey questions as fixed factors, course as a grouping factor, and median-centered grade as the dependent variable. We included responses to eight survey questions in all: Academic rank (question 1, *Rank*), whether this was a student's first ES course in college (question 2, *College Course*), interest in pursuing an ES-related career (question 3, *Career*), gender (question 4, *Gender*), number of ES courses taken in high school (question 6, *HS Courses*), whether a parent or guardian currently lives on a farm, ranch, or wooded area (question 8, *Parent Setting*), the setting of one's childhood residence (question 9, *Childhood Residence*), and the number of ES-related extracurricular activities a student participated in during high school (question 16, *Extracurricular*; Table 2).

Questions with more than two response options (e.g., *Childhood Residence*, which had three) were treated as ordinal in our analyses. Ordinal data are those for which the *order* of the categories has consistent meaning (e.g., “low,” “medium,” and “high”) but the numerical (coded) *distances* between the categories may or may not (e.g., “low” may, in reality, be closer to or further from “medium” than “medium” is to or from “high”). An inconsistent distance between categories could result in a violation of the assumption that the modeled

relationship between the dependent variable and each independent variable is approximately linear. Thus, if, as they typically are, the ordinal data are coded as equidistant (e.g., “low” = 1, “medium” = 2, and “high” = 3) when, in reality, these distances are highly unequal, assuming a linear relationship between these data and the response data may not be appropriate. Therefore, to evaluate this assumption (i.e., distances between the categories in our survey response data were approximately equal), we tested for significant ($p < 0.1$) deviations from linearity by initially including quadratic and cubic (if applicable) terms in the regression for each relevant question. All these higher-order terms proved to be non-significant (all p values > 0.1), so we dropped all such terms and were able to assume that grades change a consistent amount with each unit change in the survey response data.

We also confirmed the linear regression assumptions of residual normality and homoscedasticity via the use of diagnostic plots. Further, we checked for multi-collinearity by deriving Variance Inflation Factors for each fixed factor and found very little evidence therefor (Zuur, Ieno, and Elphick 2010). Thus, we deemed questions to be significant correlates of student grades when $p < 0.05$ and marginally significant when $0.05 < p < 0.1$. We used the Kenward-Roger approximation for denominator degrees of freedom (package: *pbkrtest*; Halekoh and Højsgaard 2014). We also derived marginal and conditional R^2 estimates for this regression model (R function: *sem.model.fits*; R package: *piecewiseSEM*; Lefcheck 2016).

To address our second research question, we performed a regression to determine if the extent to which students reported having a strong understanding of a representative ES concept before coming to college (question 15, *Understanding*) was correlated with their grades. In this regression, *Gender* and *Rank* were included as covariates, course was included as a grouping factor, and median-centered grades were the dependent variable. The construction and diagnosis of this regression were the same as for our other regression models.

Results

We obtained survey responses from 783 students across 11 introductory ES courses (48% response rate) at a large research university in the U.S. Median-centered grades were significantly correlated with the type of residence setting (i.e., rural, suburban, or urban) in which students spent most of their childhood (*Childhood Residence*, $p = 0.004$; Table 4). The regression indicated that students who reported growing up in a rural setting earned grades that were a predicted 0.10 and 0.20 IQRs higher on average than students who reported growing up in a suburban or urban setting, respectively (Table 4). Because IQRs ranged from 1.0 to 2.0 letter grades across the courses we surveyed (Table 1), a student from a rural setting would thus be predicted to earn a grade that is, on average, 0.20–0.40 letter grades higher than a student from an urban setting, depending on the course. We also observed that a larger proportion of students from urban settings earned below-median grades in their courses than did students from rural settings (33% vs. 21%, respectively; Fig. 3A).

Median-centered grades were marginally correlated with whether students reported they were currently pursuing a career in an ES-related field (*Career*, $p = 0.056$; Table 4), a proxy for strong interest in ES-related topics (see Methods, Fig. 1). The regression indicated that students who said they were pursuing an ES-related career earned grades that were a predicted 0.06 IQRs higher on average than those who said they were unsure if they were pursuing such a career and 0.13 IQRs higher than students who reported that they were not pursuing such a career (Table 4). As such, students planning to pursue an ES-related career were predicted to earn grades, on average, 0.13–0.26 letter grades higher than students not planning to pursue such a career, depending on the course. We also observed that a larger proportion of students who were not planning to pursue an ES-related career earned a grade that was below the median grade in their courses compared to students who were planning to pursue such a career (28% vs. 17%, respectively; Fig. 3B).

Academic *Rank* and *Gender* were not significantly correlated with median-centered grades (both p values > 0.101 , Table 4). Additionally, the following aspects of student background were not significantly correlated with grades: The number of ES-related courses that a student took in high school (*HS Courses*), whether this was the student's first ES course in college (*College Course*), the number of ES-related extracurricular activities a student participated in during high school (*Extracurricular*), and whether a student had a parent or guardian currently living on a farm, ranch, or woodlot (*Parent Setting*; all p values > 0.157 , Table 4).

Considering our *post priori* PCA results, which suggested that responses to the *Forest* question may have had a stronger relationship with course grades than the *Parent Setting* question (see Methods; Fig. 2), we re-ran the regression summarized above, substituting *Forest* for *Parent Setting* as the proxy for a student's frequency of pre-college interactions with natural environments. In this alternative model, a student's plans to pursue an ES-related career (*Career*; our proxy for interest in ES) became a non-significant predictor of grades ($p = 0.128$), but grades were still significantly correlated with the type of residence setting where students spent most of their childhood (*Childhood Residence*, $\beta = 0.08$, $p = 0.013$). This alternative model also showed that interactions with forests were positively but non-linearly correlated with grades (i.e., the equidistance assumption was violated, requiring the inclusion of a quadratic term for this question's response data; $\beta_{\text{FOREST}} = 0.43$, $p = 0.008$; $\beta_{\text{FOREST}^2} = -0.06$; $p = 0.028$). The regression indicated that students who reported frequent pre-college interactions with forests earned grades that were a predicted 0.73, 0.61, and 0.37 IQRs higher on average than students who reported no, seldom, or moderate pre-college interactions, respectively. As such, students with frequent pre-college interactions with forests would be predicted to earn, on average, grades 0.73–1.5 letter grades higher than students with no such pre-college interactions, depending on the course.

The relationship between a student's frequency of pre-college interactions with a forest and his or her grade is apparent when one looks at the proportions of students receiving each grade as a function of their response to the *Forest* question (Fig. 3C). Over half (53%) of the students who reported not interacting with forests at all before college received a grade below the median grade in their course. Conversely, only 29%, 23%, and 23% of students

who reported seldom, moderate, and frequent pre-college interactions with a forest received grades below the median grade of their course, respectively (Fig. 3C).

We also asked students to characterize their pre-college understanding of ecosystem processes as “lacking,” “average,” or “excellent” (question 15, *Understanding*, Table 2). A student’s reported understanding had a significant but non-linear relationship with median-centered grades ($\beta_{\text{UNDERSTANDING}} = -0.42$, $p = 0.029$; $\beta_{(\text{UNDERSTANDING}^2)} = 0.13$; $p = 0.006$). The regression model indicated that students who reported excellent understanding earned grades a predicted 0.22 IQRs higher on average than students who reported their understanding was lacking. Thus, students who reported excellent understanding were predicted to earn grades, on average, 0.22–0.44 letter grades higher than self-described lacking students, depending on the course. Fewer students who reported an excellent understanding received grades below the median grade of their course (14%) compared to students who reported average (29%) or lacking (27%) pre-college understanding (Fig. 3D).

A second self-assessment question on the survey asked whether students thought that their pre-college interactions with natural environments helped them perform better in their course (question 22, *Interaction Help*, Table 2). Forty-four percent of students reported that they thought their pre-college interactions with the natural environment did help them do better in the course, thirty-seven percent did not think these interactions helped them do better, and nineteen percent were unsure. When student responses to this question were grouped by their responses to the five questions concerning pre-college interactions with forests, soils, farms, plants, or gardens (questions 10–14, Table 2), a clear pattern emerged: Students who interacted more frequently with natural environments were more likely to report that such interactions helped them perform better in the course (Table 5). Likewise, students who reported no or seldom pre-college interactions were more likely to report that these interactions did not help them in the course (Table 5).

Discussion

In this study at a large research university in the U.S., survey data collected from 783 students revealed that students who grew up in more rural settings, had more frequent interactions with nature during childhood, and who were more interested in the subject earned higher grades, on average, than their counterparts in introductory college environmental science (ES) courses. The finding that growing up in a more rural setting was correlated with higher grades corroborates prior research conducted in college agriculture courses (Greene and Byler 2004; Mousel, Moser, and Schacht 2006), suggesting that this relationship may extend beyond agriculture courses to other environmental disciplines. Moreover, our results suggest possible connections between childhood interactions with nature, future interest in the subject, and eventual classroom performance in ES college coursework. Future work is needed to identify which elements of rural settings and prior interactions with nature influence academic performance in ES courses and whether these elements can be translated to suburban and urban settings or emulated via pedagogical practice.

It is noteworthy that students from more urban settings and those with fewer childhood interactions with natural environments underperform relative to their counterparts in introductory ES courses given that colleges should expect to see an increase in this demographic. Population growth in urban areas continues to outpace that in rural areas, and although rural areas cover 97% of the land area of the U.S., only 18% of U.S. children live in rural areas (2010 U.S. Census). In addition to increased urbanization, today's children spend less time outdoors compared to previous generations. One national survey found that while 70% of American mothers reported playing outdoors every day as a child, only 31% reported that their own children play outdoors every day (Clements 2004). This issue has been termed "nature deficit disorder," and many studies have shown that outdoor play has largely been replaced by interactions with electronic devices, such as televisions, video games, and the internet (Clements 2004; Hofferth and Sandberg 2001; Louv 2008; Zaradic and Pergams 2007). Given that children are now more likely to grow up in urban settings and less likely to have regular interactions with nature, we predict, barring a pedagogical response, that ES college courses will see increased enrollment of students who will underperform their peers who have had more past exposure to natural environments.

Indeed, our findings suggest that students who had no substantive interactions with natural environments as children could have non-trivially improved their performance in future ES college courses if they had interacted as children with natural environments just once or twice more per year. Though our data cannot explain *why* such childhood interactions with nature are important for greater success in introductory college ES courses, many prior studies have examined how the frequency of such interactions influences a child's relationship with and understanding of nature. Spending frequent time in nature and growing up in proximity to natural areas are both known to strengthen a child's environmental identity, or sense of connection to the natural environment (Cheng and Monroe 2012; Kellert 2002; Tugurian 2014). In turn, a strong environmental identity is often associated with increased interest in the natural environment and thus with pro-environmental behaviors (Blatt 2013; Cheng and Monroe 2012; Frantz and Mayer 2014) and greater environmental knowledge (Bögeholz 2006). How exactly frequent exposure to elements of the natural environment may link to increased academic performance in the classroom remains unclear, however. Given the plausibility of these and other alternative linkages, we cannot recommend specific pedagogic interventions based on the resolution of our results alone, but our results do support the validity of further exploration into how these linkages may inform future pedagogical practice.

Recent work has also highlighted the importance of the development of student mental models of the environment. Mental models are internal representations used to make sense of the world, which individuals construct and modify via a coupling of prior and current experiences. Holding well-developed mental models allows students to more easily insert new knowledge into their constructs (Greca and Moreira 2000; Jones et al. 2011; Libarkin, Beilfuss, and Kurdziel 2003), and thus the state of one's mental model is likely associated with performance in the classroom. Consistent with our findings, evidence suggests that mental models of the environment are fixed in childhood and strongly influenced by experiences in nature (Strommen 1995; Wuellner, Vincent, and Felts 2017), whereas ES coursework later in life has been previously shown to have little to no influence in altering

such mental models (Huxster, Uribe-Zarain, and Kempton 2015; Liu and Lin 2015; Wuellner, Vincent, and Felts 2017).

By extension, a small number of studies found differences between the environmental mental models of children from rural and urban settings (Shepardson et al. 2007; Tsurusaki and Anderson 2010). Shepardson et al. (2007) observed that students from urban areas were more likely to perceive the natural environment as “a place impacted or modified by human activity” compared to students from rural or suburban areas, the majority of whom viewed the environment as “a place where animals and plants live.” The authors also noted that textbooks may favor or reinforce mental models that are more commonly held by children from rural or suburban areas, but it is not otherwise clear how these differences in mental models could impact subsequent performance in ES college courses. The need for additional research to understand these linkages is critical given the magnitude of urban growth and the rate at which students are dropping out of STEM programs.

We also found that students who interacted more frequently with natural environments during childhood were more likely to report these interactions as helpful to their course performance. Because these students apparently recognize an educational benefit of childhood interactions with nature, a logical next step would be to examine the efficacy of infusing ES curricula with outdoor learning experiences such as field trips, which, depending on their structure (DeWitt and Storksdieck 2008), have been shown to produce both short- and long-term ES knowledge gains (Farmer, Knapp, and Benton 2007; Judson 2011; Orion and Hofstein 1994; Prokop, Tuncer, and Kvasniák 2007). Alternatively, students might find that unstructured experiences in nature, shown to be less common among recent generations (Kemple et al. 2016, Louv 2008), are equally helpful for success in ES courses, as one study found that a child’s ability to learn in an outdoor ES program depended on an *a priori* comfort in nature (Kossack and Bogner 2012). Regardless of the context, this result warrants additional study, especially at large research universities where efficiencies in teaching are scrutinized (Bok 1992).

Consistent with our predictions, student grades were also marginally correlated with self-reported interest in ES (using plans to pursue an ES-related career as a proxy). This finding is not new, as many studies show that interest in course content is a robust predictor of student performance across both subjects and grade levels (Ferrell, Phillips, and Barbera 2016; Harlow, Harrison, and Meyertholen 2014; Schiefele, Krapp, and Winteler 1992). Taken in total, these results argue that ES course instructors can elevate student performance by employing teaching practices targeted at increasing student interest. These practices could include linking the relevancy of course material to students’ personal lives (Hulleman et al. 2010; Hulleman and Harackiewicz 2009), connecting course content to student interests (Taylor, Mitchell, and Drennan 2009), and transforming course structure from content-centered to learner-centered (Russell et al. 2016). As an example, Russell et al. (2016) successfully used active learning approaches to increase student interest in an introductory college ES course such that students earned final grades that were 0.75 letter grades higher than students in the traditional lecture-based course. Our results add to the ever-growing evidence that student interest plays a consequential role in STEM classroom performance, now extended to ES coursework specifically.

It is also important to note that one might expect higher grades to be associated with both childhood exposure to nature and interest in ES topics because spending time in nature is strongly correlated with interest in the natural environment (Bögeholz 2006, Kals 1999, Cheng & Monroe 2012, Chawla 2007). Thus, one hypothesis is that there is a pathway from exposure to nature to interest in ES to academic success in ES courses. More work is needed to assess such a model and its implications, such as exploring the types of interventions that could place children on or return them to this path and whether such experiences need occur before some critical age.

We did not find evidence that a student's amount of prior ES-related coursework was correlated with their final ES course grade in the introductory courses surveyed. This outcome was surprising because prior coursework in a subject was shown to correlate with higher grades in future courses in other STEM fields (Harlow, Harrison, and Meyertholen 2014; Loehr et al. 2012; Sadler and Tai 2001; Schwartz et al. 2009). We offer several potential explanations for this contrasting result. First, some research indicates that it is not prior coursework *per se*, but academic *success* in prior courses that predicts future academic success (Brown, White, and Power 2017; Nordstrom 1990; Pike and Saupe 2002; Sadler and Tai 2007), and we did not ask students to report their level of success in prior ES courses. Second, the interdisciplinary nature of environmental science may make knowledge transfer difficult between courses. For instance, in comparatively linear disciplines such as mathematics, advanced coursework often scaffolds directly on prior coursework. However, it might be less reasonable to assume that students who took a wildlife ecology course, for example, would as a direct result, be better prepared for a course on weather and climate.

Alternatively, the lack of correlation between prior ES coursework and grades may stem from an overemphasis on content coverage in ES courses rather than on unifying concepts. This hypothesis is supported by prior studies on student mental models of the environment. Most children and undergraduates, including ES majors, have poorly developed mental models of the environment, focused on objects and characteristics rather than on relationships and processes that connect them (Liu and Lin 2015; Shepardson et al. 2007; Tsurusaki and Anderson 2010; Wuellner, Vincent, and Felts 2017). In other words, students may know about the "who" and "what" of an environment (e.g., deer, palm tree, igneous rock, and cumulonimbus cloud) but much less about the "how" or "why" (e.g., predator-prey dynamics, ecological succession, and atmospheric convection). Focusing ES coursework more heavily on crosscutting concepts, such as systems modeling or matter and energy flow (National Research Council 2012), rather than on declarative knowledge might provide a conceptual framework that is more transferable for students across the spectrum of ES courses that is typical of this program of study.

Lastly, we found a positive relationship between final grade and a student's self-reported pre-college understanding of a representative ES concept (ecosystem processes). If we assume that a strong understanding of central ES concepts aids student performance in ES courses, then students who self-reported excellent understanding were relatively accurate at self-assessing because most of these students earned above-median course grades. Self-reported understanding may also reflect ES self-efficacy, defined as a student's confidence in his or her academic success in ES-related courses, as high self-efficacy is a strong predictor

of academic success (Aleta 2016; Michaelides 2008; Pajares and Graham 1999). However, many students who reported an average or lacking understanding also earned above-median grades, suggesting that these students underestimated their understanding, which is often true of high-performing students (Ehrlinger et al. 2008; Kruger and Dunning 1999). Alternatively, these students may have been able to overcome their insufficient understanding through compensatory behaviors (e.g., by spending extra time studying).

Further work is needed to assess the universality of our findings, and because our results are correlational, questions of cause and effect remain, including why students who grow up in urban settings are more likely to underperform their counterparts and how interactions with natural environments contribute to ES course performance. Specifically, there is robust interest in improving student experiences in gateway courses to increase retention in college STEM programs, including ES programs (Gasiewski et al. 2012; Graham et al. 2013; Haak et al. 2011), with respect to which our results identify areas on which to focus innovations in teaching. For example, improved teaching practices might include focusing ES curricula on crosscutting concepts and incorporating outdoor learning activities, the latter of which could simultaneously increase a student's amount of substantive interaction with nature, interest in ES, and ES foundational knowledge (Bögeholz 2006; Chawla 2007; Cheng and Monroe 2012; Kals, Schumacher, and Montada 1999).

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Figure 1.

Proportions (stacked bars) of undergraduate students in surveyed introductory college environmental science courses at a large research University as a function of their responses to two questions: 1) whether they were currently pursuing a career in an environmental science-related field (colored regions) and their interest in the natural environment (x-axis). Regions with proportions > 0.04 are labeled (white text) with their proportions. The two variables were highly correlated (Pearson's $r = 0.517$, $p < 0.001$), suggesting the career question was a valid proxy for strong interest in ES topics. Sample sizes for each group are in Table 2.

Figure 2.

Biplot of a Principle Components Analysis showing the relationships between median-centered grade data and the frequency of pre-college interactions students reported having had with several components of the natural environment (N = 769 respondents). The two principal components that captured the largest percentages of the variance are shown. Vectors represent: 1) median-centered grades (GRADES); 2) the amount of substantive pre-college interactions students reported having had with forests (FOREST), soil (SOIL), gardens (GARDEN), farms (FARM), and plants (PLANTS; questions 10 through 14, Table 2); and 3) whether or not a parent or guardian was currently living on a farm, ranch, or wooded area (PARENT).

Figure 3.

Proportions (stacked bars) of undergraduate students at a large research University in surveyed introductory college environmental science courses receiving each grade (colored regions) as a function of their responses to four survey questions (x-axes). Grades were median-centered (i.e., the median grade in every course was set to 0, shown in gray). The question in panel B was used as a proxy for strong interest in ES-related topics. The proportion of students in each group receiving the median grade in their respective courses is labeled in white and bracketed by solid black lines. IQR stands for “inter-quartile range,” which is the distance between the 25th and 75th grade quartiles in a course (1 to 2 letter grades, depending on the course). Sample sizes are listed in Table 2.

Table 1.

Descriptive statistics for the surveyed introductory college environmental science courses (n = 11) in this study.

Course	Term ¹	Total students	Total responses (% of total)	Median grade	Grade IQR ²
A	F-12	53	31 (58.5%)	3.5	1.0
B	S-12	371	107 (28.8%)	3.0	1.5
C	S-12	173	92 (53.2%)	3.5	1.0
D	F-12	40	29 (72.5%)	3.5	1.0
E ³	F-12	185	86 (46.5%)	3.0	1.0
E	S-12	157	60 (38.2%)	3.0	1.0
F	F-12	290	168 (57.9%)	3.0	1.0
G	S-12	73	50 (68.5%)	3.0	1.0
H	S-12	168	69 (41.1%)	3.5	1.5
I	F-12	42	29 (69.0%)	3.0	1.8
J	S-12	81	62 (76.5%)	3.0	2.0
Totals		1633	783 (47.9%)		

¹ S and F stand for Spring and Fall, respectively.

² IQR stands for inter-quartile range, which is the distance between the 25th and 75th grade quartiles in a class.

³ Course E was surveyed twice, once each in two consecutive semesters.

Table 2.

Survey questions administered to students in introductory college environmental science courses in this study. Statistical codes for question response levels are listed in parentheses; the number of students who chose each level is in square brackets.

Question	Abbr.	<i>I</i> Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
1. What is your college rank by credit hours?	<i>Rank</i>	Freshman (1) [154]	Sophomore (2) [246]	Junior (3) [203]	Senior (4) [177]	
2. Is this your first environmental-science related course in college?	<i>College Course</i>	Yes (0) [455]	No (1) [325]			
3. Are you targeting a career in an environmental science field?	<i>Career</i>	Yes (2) [167]	No (0) [510]	Currently unsure (1) [101]		
4. Gender?	<i>Gender</i>	Male (1) [333]	Female (0) [448]	Decline to answer (NA)		
5. How would you describe the community (in terms of approximate population) where you attended high school? The population of Madison, WI is currently around 200,000 persons.	<i>HS Setting</i>	Urban (> 100,000 people) (1) [176]	Suburban (100,000–20,000 people) (2) [364]	Rural (< 20,000 people) (3) [242]		
6. How many courses did you take in High School that were directly related to environmental science?	<i>HS Courses</i>	0 (0) [252]	1 (1) [277]	2 (2) [169]	3 (3) [78]	
7. Please list the place in which you lived the longest as a kid. Would you define it as rural?	--	(blank)	(blank)			
8. Is at least one parent/guardian presently living on a farm, ranch (raising range animals), or wooded area?	<i>Parent Setting</i>	Yes (1) [148]	No (0) [634]			
9. What type of setting did you spend the majority of your childhood in?	<i>Childhood Residence</i>	Urban (> 100,000 people) (1) [184]	Suburban (100,000–20,000 people) (2) [346]	Rural (< 20,000 people) (3) [253]		
10. Estimate the amount of substantive interaction you have had with the forest before coming to college?	<i>Forest</i>	Not at all (0)	Seldom (< 2x per year) (1)	Moderate (3–5x per year) (2)	Frequent (> 5x per year) (3)	
11. Estimate the amount of substantive interaction you have had with the soil (dirt) before coming to college?	<i>Soil</i>	Not at all (0)	Seldom (< 2x per year) (1)	Moderate (3–5x per year) (2)	Frequent (> 5x per year) (3)	
12. Estimate the amount of substantive interaction you have had a farm before coming to college?	<i>Farm</i>	Not at all (0)	Seldom (< 2x per year) (1)	Moderate (3–5x per year) (2)	Frequent (> 5x per year) (3)	
13. Estimate the amount of substantive interaction you have had with plants before coming to college?	<i>Plants</i>	Not at all (0)	Seldom (< 2x per year) (1)	Moderate (3–5x per year) (2)	Frequent (> 5x per year) (3)	
14. Estimate the amount of substantive interaction you have had with a garden before coming to college?	<i>Garden</i>	Not at all (0)	Seldom (< 2x per year) (1)	Moderate (3–5x per year) (2)	Frequent (> 5x per year) (3)	
15. Characterize your understanding of ecosystem processes (e.g., carbon cycle) before coming to college?	<i>Understanding</i>	Lacking (1) [182]	Average (2) [482]	Excellent (3) [112]		

Question	Abbr.	Choice 1	Choice 2	Choice 3	Choice 4	Choice 5
16. How many extracurricular activities related directly to the environment did you take part in during high school?	<i>Extracurricular</i>	0 (0) [437]	1 (1) [200]	2 (2) [80]	3 (3) [57]	
17. Who in your background was the last to own a farm?	<i>Own Farm</i>	Parent [79]	Grandparent [207]	Great grandparent [146]	Uncle [206]	Other or none [133]
18. Who in your background was the last to own a woodlot or have a home in the woods?	<i>Own Woodlot</i>	Parent [221]	Grandparent [165]	Great grandparent [27]	Uncle [237]	Other or none [124]
19. Who in your family background taught you about environmental science (how ecosystems work, not in terms of social ideals related to the environment; circle all that apply)?	--	(14 choices)				
20. What type (pick one) of setting would you like to be living in 10 years from now?	--	Urban [279]	Suburbs [268]	Rural [216]		
21. When you played with friends as a kid, how did you get there (choose the most dominant)?	--	Walk [191]	Bike [265]	Drive [272]	Public transportation [13]	Other [2]
22. Do you think your interaction with the natural environment before college helped you in this course?	<i>Interaction Help</i>	Yes (3) [310]	No (1) [258]	Uncle (2) [129]		
23. How would you rate your interest in the natural environment?	<i>Environment Interest</i>	Very interested (3) [231]	Interested (2) [275]	Indifferent (1) [108]	Not interested (0) [23]	

¹The choices for question 19 were: a) Mother, b) Father, c) Sibling, d) Grandmother, e) Grandfather, f) Uncle, g) Aunt, h) Great grandparent, i) Family friend, j) Teacher, k) Scout leader, l) religious leader, m) none, n) other (or blank).

²Questions 22 and 23 were administered to only 10.5 and 9.5 of the 11 surveyed courses, respectively (a half course indicates that these questions were administered to only one of two course sections).

Table 3.

Correlation matrix of responses to all survey questions in this study that could be coded numerically. The question order across columns is the same as down rows. Question numbers and abbreviations are consistent with those in the text and in Table 2. High correlations were used to justify the use of some questions as proxies for others in the analyses (see Methods).

Question number (Abbr.)	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	22	23
1 (Rank)	1																		
2 (College Course)	0.49	1																	
3 (Career)	-0.01	0.50	1																
4 (Gender)	0.07	0.04	-0.08	1															
5 (HS Setting)	0.02	0.08	0.07	-0.01	1														
6 (HS Courses)	0.02	0.20	0.13	0.05	0.11	1													
8 (Parent Setting)	-0.01	0.07	0.17	0.12	0.59	0.33	1												
9 (Childhood Residence)	-0.06	0.00	0.04	-0.02	0.89	0.09	0.62	1											
10 (Forest)	-0.03	0.20	0.28	0.15	0.31	0.14	0.60	0.34	1										
11 (Soil)	0.01	0.27	0.31	0.07	0.27	0.22	0.60	0.31	0.67	1									
12 (Farm)	-0.01	0.15	0.15	0.02	0.43	0.21	0.66	0.46	0.51	0.54	1								
13 (Plants)	0.04	0.23	0.35	-0.01	0.23	0.16	0.57	0.26	0.61	0.77	0.58	1							
14 (Garden)	0.02	0.17	0.24	-0.13	0.25	0.13	0.50	0.28	0.47	0.63	0.52	0.84	1						
15 (Understanding)	-0.01	0.19	0.29	0.16	0.12	0.33	0.32	0.12	0.33	0.35	0.22	0.39	0.32	1					
16 (Extracurricular)	-0.05	0.09	0.37	0.01	0.06	0.30	0.25	0.10	0.35	0.45	0.32	0.38	0.31	0.42	1				
17 (Own Farm)	-0.02	0.00	0.00	0.03	0.24	0.13	0.28	0.25	0.14	0.14	0.41	0.14	0.16	0.03	0.03	1			
18 (Own Woodlot)	0.02	0.03	0.02	0.05	0.23	0.09	0.34	0.26	0.31	0.19	0.32	0.21	0.19	0.08	0.14	0.39	1		
22 (Interaction Help)	-0.10	0.03	0.38	0.14	0.11	0.19	0.39	0.14	0.40	0.38	0.32	0.39	0.25	0.32	0.39	0.09	0.16	1	
23 (Environment Interest)	0.06	0.38	0.78	0.03	0.11	0.16	0.37	0.15	0.51	0.52	0.25	0.51	0.39	0.36	0.44	-0.01	0.15	0.52	1

Table 4.

Results from a multiple linear mixed-effects regression assessing relationships between the responses of undergraduate students ($N = 754$ responses) in introductory college environmental science courses to several specific survey questions (fixed factors) and the median-centered grades those students received in the course (dependent variable).

Question ¹	β	df^2	t	p^3
<i>Intercept</i>	-0.37	317.7	-2.525	0.012
<i>Rank</i>	0.03	717.5	1.326	0.185
<i>College Course</i>	0.03	744.4	0.524	0.601
<i>Career</i>	0.06	723.5	1.915	<i>0.056</i>
<i>Gender</i>	0.08	743.8	1.643	0.101
<i>HS Courses</i>	-0.04	743.9	-1.481	0.157
<i>Parent Setting</i>	-0.02	742.7	-0.300	0.765
<i>Childhood Residence</i>	0.10	741.1	2.924	0.004
<i>Extracurricular</i>	-0.0012	744.4	-0.046	0.963

¹The question text as well as an explanation of how question response levels were coded is available in Table 2.

²We used the Kenward-Roger approximation for denominator degrees of freedom (Halekoh and Højsgaard 2014).

³Significant ($p < 0.05$) and marginally significant ($0.05 < p < 0.1$) p values are shown in bold and in italics, respectively.

Table 5.

Percentages of students reporting whether they thought their pre-college interactions with the natural environment helped them perform better in their introductory environmental science course as a function of the frequency of pre-college interactions these students reported having had with components of the natural environment.

Natural environment component	Interaction frequency	Do you think your interactions with the natural environment helped you in this course?			# Respondents
		No	Unsure	Yes	
Forests	None ¹	68.6%	14.3%	17.1%	35
	Seldom	52.3%	21.6%	26.1%	153
	Moderate	38.4%	25.3%	36.4%	198
	Frequent	24.9%	12.9%	62.1%	309
	# Respondents	257	128	310	² 695
Soil	None	55.7%	19.6%	24.7%	97
	Seldom	43.8%	22.9%	33.3%	210
	Moderate	41.4%	20.7%	37.9%	145
	Frequent	21.4%	13.2%	65.4%	243
	# Respondents	258	129	308	² 695
Farms	None	49.8%	19.9%	30.3%	211
	Seldom	38.7%	17.0%	44.3%	253
	Moderate	26.9%	25.0%	48.1%	104
	Frequent	21.3%	14.2%	64.6%	127
	# Respondents	258	129	308	² 695
Plants	None	66.7%	27.3%	6.1%	33
	Seldom	50.0%	24.4%	25.6%	156
	Moderate	39.2%	19.1%	41.8%	194
	Frequent	26.1%	14.3%	59.6%	314
	# Respondents	258	129	310	² 697
Gardens	None	57.4%	20.4%	22.2%	54
	Seldom	44.5%	20.2%	35.3%	173
	Moderate	38.1%	17.8%	44.2%	197
	Frequent	27.6%	17.6%	54.8%	272
	# Respondents	258	129	309	² 696
³ Avg. median-centered grade		0.039	0.047	0.117	

¹Percentages are calculated across rows. "None" refers to students who selected the "Not at all" response level.

²Totals vary because of variation in the numbers of students who responded to both respective questions.

³A value of 0 represents the median grade in a course and values above 0 represent grades that are that many inter-quartile ranges above the median grade.