RELATIONSHIPS BETWEEN STRUCTURE AND FUNCTION: SYSTEM STRUCTURE MATTERS WHETHER YOU ARE IN A WETLAND OR A COLLEGE CLASSROOM

BY

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DEDICATION

I dedicate this dissertation to all of my past and future students, without whom I never would have been motivated to embark upon the education-based research described in Part II.

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FOREWORD

My dissertation is in two parts; the first focuses on methane cycling dynamics in freshwater wetland soils and the second focuses on student dynamics in an undergraduate soil science course. While each half is very different, the central concept underlying both is a systems focus on structure/function relationships.

Part I details my role in two studies on freshwater wetlands (the system). In Chapter 1 I explore differences in microbial production and consumption of methane (function) due to wetland type (structure). In Chapter 2 I explore differences in the competing microbial processes of methane production and iron reduction (function) due to plant community composition and richness (structure). This chapter has been published in *Ecosphere* (Andrews et al. 2013).

Part II of my dissertation describes my research on the re-structure of an introductory soil science course from a traditional lecture-based course with a separate lab to a studio-style course (Studio Soils) where the lecture and lab were combined and integrated with collaborative learning. In Chapter 3 I focus on student performance (function) in the course before and after modification (structure). In Chapter 4 I explore the Studio Soils experience (the system) by looking at relationships between students' perspectives (function), and ways of knowing in the newly restructured course (structure). Chapter 5 is an opinion article that makes a case for the studio learning environment by synthesizing findings from Chapters 3 and 4.

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RELATIONSHIPS BETWEEN STRUCTURE AND FUNCTION:

SYSTEM STRUCTURE MATTERS WHETHER YOU ARE IN A WETLAND OR

A COLLEGE CLASSROOM

by

Sarah Elizabeth Andrews

University of New Hampshire, September, 2014

Part I of this dissertation describes two research projects I undertook to understand how structure influences function in freshwater wetlands. In the first study I tested the hypothesis that wetland structure (created versus natural) would influence function (methane cycling). Created wetlands had reduced rates of potential methane production and potential methane oxidation compared to natural wetlands; this was most likely explained by differences in edaphic factors that characterized each wetland, particularly soil moisture and soil organic matter. In the second study (Andrews et al. 2013), I tested the hypothesis that plant community structure (functional group composition, richness, presence/absence) would influence function (methane and iron cycling) in wetland mesocosms. Plant functional group richness was less important than the type of vegetation present: the presence of perennial vegetation (reeds or tussocks) led to increased rates of potential iron reduction compared to when only annual vegetation was present.

Part II of this dissertation describes research I undertook to understand how structure influences function in an undergraduate soil science course. In the first study I tested the hypothesis that course structure (traditional versus studio) would influence function (student performance) in the course. Students in the studio course outperformed students in the traditional course; there was also a decrease in the fail rate. In the second study I looked at students' perspectives on their learning and experiences (function) in the studio course and asked whether students' epistemological development influenced this function. Interviews with students revealed that active learning, the integrated nature of the course, community, and variety of learning and assessment methods helped student learning. Students' epistemological development (interpreted from the Measure of Epistemological Reflection) permeated much of what they spoke about during the interviews. There was also evidence that the studio structure may help promote epistemological growth via "sneaky learning" and an expanded role of peers.

The studies in Part I show that differences in structure affect function in freshwater wetland systems and the studies in Part II show that structure affects function in an undergraduate introductory soil science course. Thus, system structure matters whether you are in a wetland or a college classroom.

PART I: METHANE DYNAMICS IN FRESHWATER WETLANDS

INTRODUCTION TO PART I

In the field of ecology there is great concern over the consequences of the global loss of species and shifts in community composition. The current loss of species is primarily due to human activities and is far above background levels (Vitousek et al., 1997). Human land use in particular can alter the structure and functions of ecosystems, with land transformations a primary cause of biodiversity loss (Findlay and Houlahan, 1997; Casteletta et al., 2000; Laurance et al., 2002, Horgon, 2005). Other anthropogenic causes for species loss include climate change, changes in global biogeochemistry, increasing rate of invasive species, and over utilization of resources (for review see Vitousek et al., 1997). This global loss of species has prompted an interest in studying the effects of biodiversity on ecosystem functions. Much of the early biodiversity research focused on plant productivity in grassland systems, leaving the field open to explorations of aboveground-belowground interactions in other ecosystems. Wetlands were of particular interest to me because they provide a number of valuable services, including biodiversity support, water quality maintenance and improvement, flood control, and carbon management (Zedler and Kercher 2005). In addition, wetlands are estimated to be the single largest natural source of methane to the atmosphere (Christensen et al. 2003, Shindell 2004, Denman et al. 2007), but they also consume more methane than any other single sink (Frenzel 2000).

Wetlands provide such a unique environment because the waterlogged conditions slow down oxygen diffusion and provide an anaerobic environment for methane production. Plants adapted for survival in wetlands provide a substrate for methanogens through root turnover and root exudates. However, among the mechanisms that plants have of surviving in waterlogged soils is the formation of aerenchyma, which allows the diffusion of oxygen to their roots. This causes the creation of an oxygenated rhizosphere, providing an aerobic environment that inhibits methanogenesis and allows methanotrophs to consume at least a portion of the methane produced by methanogens (for review see Conrad 1996 and Le Mer and Roger 2001). While the ways that plants can influence methane cycling are well understood, the degree to which plants contribute to methane oxidation, methane production, and plant transport of gases are less well understood. Therefore, it is still uncertain as to how changes in plant community structure (richness, diversity, biomass, etc.) will affect these components of the methane cycle and thus, what affect these changes might have on methane emissions. In the face of global climate change it is imperative that we gain a better understanding of the factors that control methane emissions from wetlands. Such an understanding could be critical in determining best management practices for wetland ecosystems and could contribute vital data to climate change models.

These concerns provided the framework for my research on the effects of plant community structure on methane cycling in freshwater wetlands, part of a collaborative project with colleagues at Ohio State University, which I describe in Chapters 1 and 2. The first component of my research was part of an observational field study of created and natural emergent freshwater marshes in central Ohio, USA (2005-2007). The primary goal of this project was to determine whether plant diversity or plant community composition played a greater role in mediating carbon cycling. My primary role in this project was to collect soil samples and conduct laboratory incubations to measure rates of methane oxidation and production. These data were incorporated into models that also included plant diversity, plant community composition, above and belowground plant biomass, and in situ methane flux, the findings of which have already been published (Schultz et al. 2011). Therefore, in Chapter 1 I focus on an aspect of the study not covered in the published paper: the role of wetland type (created versus natural) on methane cycling.

The second component was part of an experimental wetland mesocosm study (2007-2009). The overarching goal of this project was similar to the field study (to explore the relationships amongst plant community structure and carbon cycling dynamics in freshwater wetlands). However, in addition to being an experimental study rather than an observational study, the mesocosm study looked at differences in plant diversity and community composition at the functional group level (rather than the species level). My part of this project focused on the competing processes of methane production and iron reduction (different bacteria compete for the same resources during anaerobic decomposition of organic matter). Chapter 2 is a reprint of a manuscript that has recently been published in *Ecosphere* (Andrews et al. 2013).

CHAPTER 1

A COMPARISON OF POTENTIAL METHANE OXIDATION AND POTENTIAL METHANE PRODUCTION IN CREATED AND NATURAL FRESHWATER DEPRESSIONAL WETLANDS OF CENTRAL OHIO, USA

Abstract

Natural wetlands, which provide many valuable ecosystem services, are being lost at an alarming rate. While rates of wetland destruction have declined and rates of wetland restoration and creation have increased, much of the data collected from created and restored wetlands suggest that the functions, and thus the services, that wetlands provide are not being replaced. While carbon storage and cycling have consistently been shown to be relatively lower in created wetlands, few studies have looked at methane cycling specifically. To address this gap in knowledge I compared rates of potential methane oxidation and potential methane production measured on soils collected from two created and two natural wetlands. Fifteen to 17 plots were selected across a range of plant species richness in each wetland and soil cores (0-30 cm) from each plot were collected and separated into two depth increments (0-10 and 10-30 cm). Soils from each plot and depth were incubated in the lab to determine rates of potential methane oxidation and potential methane production. Soil organic matter, soil moisture, and soil pH were also determined for each soil sample. I found that potential methane oxidation, potential methane production, soil organic matter, and soil

moisture were all higher, and soil pH was lower, in natural wetlands than in created wetlands. Differences in rates of potential methane oxidation and potential methane production between created and natural wetlands are most likely explained by differences in soil moisture and soil organic matter content.

Introduction

Wetlands make up less than 1% of global land area but contribute approximately 15% of the global estimate of annual services (Costanza et al. 1997). However, awareness of the importance of such services only began to increase in the 1970s; prior to that time, many practices leading to wetland losses were subsidized by the federal government (Dahl and Allord 1990). From the time the United States was colonized until the mid-1980s, 22 states had lost ≥ 50% of their wetlands, principally from conversion to agricultural land (Dahl and Allord 1990). Efforts at restoring wetlands and minimizing wetland losses began increasing in the 1980s (Dahl and Allord 1990); by 1997 there was an 80% reduction in the annual rate of wetland loss compared to the previous decade (Dahl 2000), and by 2004 net gains in wetland acreage were surpassing losses (Dahl 2006). Unfortunately, these gains were primarily due to substantial increases in pond acreage (Dahl 2006).

Despite a reduction in rates of wetland area lost and increases in wetland restoration/creation efforts, growing research indicates that restored and created wetlands do not always exhibit the same biogeochemical functions as natural wetlands (Ballantine and Schneider 2009, Hossler and Bouchard 2010, Hossler et al. 2011, Moreno-Mateos et al. 2012). Thus, the acres of created ponds that accounted for the net gain in wetland acreage from 1998 to 2004 may not functionally replace the natural wetlands lost (Dahl 2006). In particular, carbon storage and cycling have consistently been shown to be slow to recover to rates seen in natural reference wetlands. For example, Hossler and Bouchard (2010) found reduced soil organic matter (SOM) in created wetlands (3-8 years old) relative to natural systems, and Hossler et al. (2011) found that created wetlands (<1 to 39 years old) cycled 70-90% less carbon through mineralization than natural wetlands. Ballantine and Schneider (2009) also found that SOM in restored wetlands were less than half that of the natural wetlands studied, even 55 years after restoration, and Moreno-Mateos et al. (2012) found that storage and cycling of carbon were reduced in created/restored wetlands relative to natural wetlands even a century after restoration. Given the potential lack of carbon storage/cycling functionality in created wetlands, it is increasingly important that we better understand factors mediating such functions. Methane cycling is of particular interest because of methane's importance as a greenhouse gas and because wetlands consume more methane than any other single sink (Frenzel 2000), but are also the largest natural source of methane to the atmosphere (Denman et al. 2007).

My objective was to study the effects of wetland type (created versus natural), soil depth (0-10 cm versus 10-30 cm), and plant species richness on potential methane oxidation, potential methane production, and environmental soil properties (moisture, SOM, and pH). Because others have found that created wetlands generally have lower SOM than natural wetlands (Ballantine and Schneider 2009, Hossler et al. 2010) and cycle carbon more slowly than natural wetlands (Hossler et al. 2011, Moreno-Mateos et al. 2012), I hypothesized that methane production, methane oxidation and soil organic matter would be lower in created wetlands than in natural wetlands. I also hypothesized that potential methane oxidation would decrease and potential methane production would increase with soil depth because others (Keller et al. 2005) have found similar results, likely due to declining oxygen availability with depth. Methane emissions have been shown to decline with increased plant species richness (Bouchard et al. 2007); this relationship was attributed to greater root production and rooting depth in communities with greater richness (and thus increased rhizospheric oxidation) which could lead to enhanced methane oxidation and/or reduced methane production. Therefore, I also hypothesized that methane production would decrease with increased plant species richness while methane oxidation would increase.

Materials and Methods

Site description and sampling design

Two natural and two created wetlands were selected in central Ohio, within 65 miles of Columbus. The two natural wetlands were Ballfield (Bladensburg, Knox County) and Calamus Swamp (Circleville, Pickaway County). One created wetland is in the Big Island Wildlife Area (Marion, Marion County), and the other is at the Clover Groff Natural Area (Hilliard, Franklin County). Both created wetlands were 7 years old at the time of sampling. The portion of the study reported here focused on central areas of each wetland that are flooded for longer periods and/or are flooded to greater depths compared to the wetland fringes. These areas are vegetated primarily with clonal dominant plant communities. The center area of Ballfield has deep open water with a dense stand of *Typha* spp. on one edge. Dominant vegetation in this area that is not overtaken by *Typha* are *Scirpus validus*, *Juncus effusus*, and *Polygonum hydropiperoides*. Calamus Swamp is a roughly circular basin that used to be mostly open water at its center, but in the last decade has been overtaken by wetland vegetation, especially *Typha angustifolia* and *Sparganium eurycarpum*. The perimeter of this central area is surrounded by thick bushes of *Cephalanthus occidentalis*. The Big Island Wildlife Area has two deep channels that periodically flood over the higher ground. Off of the main channel is a wetland area that is flooded for longer durations and is dominated by the genera *Typha*, *Eleocharis*, and *Scirpus*. The central area of the wetland at Clover Groff has a small permanently flooded pool at one end. Spreading out from the pool is short, sparse wetland vegetation dominated by *Scirpus pungens* and *Pontederia cordata*.

In mid-July 2006 15 – 17 plots were selected at each wetland across a range of plant species richness, including no-plant controls where possible. Plant species richness per plot ranged from 0-5 in Big Island, 0-6 in Clover Groff, 0-11 in Ballfield, and 1-6 in Calamus. Further details on site selection, sampling design, and soil sampling are reported in Schultz et al. 2011.

Soil sampling and analysis

Details on soil sampling and analysis are reported in Schultz et al. 2011. Briefly, after aboveground biomass was removed, two soil cores (7 cm diameter, 30 cm depth) were collected from each plot and separated into two depth increments (0-10 cm and 10-30 cm) before being bulked. Within five days of collection, soil cores were homogenized and subsamples (200-300 g) were shipped overnight to the University of New Hampshire and stored at 4°C until analysis. Soil moisture was determined by drying subsamples at 105°C to constant mass. The dried soils were then combusted in a muffle oven at 450°C for 6 hours to determine soil organic matter by loss-on-ignition. Soil pH was determined on 1:2 soil : deionized water slurries.

Methane oxidation and production potentials

The methods used to determine potential methane oxidation and potential methane production were modified from methods reported by others (Krüger et al. 2002; Megonigal and Schlesinger 2002) and are reported in detail in Schultz et al. 2011. Briefly, for potential methane oxidation, soils (10 g wet weight ± 0.1 g) were loaded into 475 mL, wide-mouth mason jars, mixed with 10 mL deionized water, capped loosely with lids fitted with red rubber septa, and placed on an orbital shaker overnight at room temperature. The following morning jars were flushed with compressed air for 4 min to ensure uniform conditions, sealed, and amended with methane (final concentration ranged from 9-13 ppm_v). Jars were placed back on the orbital shaker until headspace samples were taken at 4, 8, 12, and 24 hours. Soils for potential methane production were treated similarly to those for potential methane oxidation with the following exceptions. Soils were prepared in an anaerobic N_2 filled chamber and jars were sealed inside the chamber before being placed in a 25°C incubator overnight. The following morning jars were flushed with ultrapure N_2 for 4 min to ensure anaerobic conditions and placed in a 25°C incubator until headspace samples were taken at 24, 48, 72, and 96 hours.

For potential methane oxidation and potential methane production, headspace samples were stored in evacuated 20 ml vials at 4°C until the contents could be analyzed for methane concentration (within 2 weeks of headspace sample collection). Triplicate blanks (20 ml deionized water) were treated and sampled identically to the soil samples except the headspace samples were only taken at time zero (when jars were sealed) to estimate starting conditions in the jars. Headspace samples were analyzed for methane concentration using a gas chromatograph equipped with a flame ionization detector (Shimadzu GC-8A) and a 1-mL sample loop. The carrier gas was N_2 with a flow of 30 mL/min. Standardization was done using a calibrated breathing air cylinder based on NOAA ESRL standards.

Statistical analyses

Potential methane oxidation and potential methane production rates were determined by linear regression (PROC REG, SAS 9.3). Rates were accepted for significant regressions with $P \leq 0.05$ and $r^2 \geq 0.75$. Rates that did not meet these criteria were not used and were treated as missing data (70% of potential methane oxidation and potential methane production rates met these criteria). To test for the effects of wetland type (created, natural), soil depth (0-10 cm, 10-30 cm), and plant species richness (0 – 11 species), separate linear mixed effects models (LME) were done with potential methane oxidation, potential methane production, soil moisture, soil organic matter, or soil pH as the dependent variable (PROC MIXED, SAS 9.3). Potential methane oxidation and potential methane production rates were log transformed to adjust for heteroscedasticity and non-normality. Plant species richness was treated as a continuous variable. Soil depth was treated as a split-plot rather than a repeated measure because there were only two depths sampled. Site (four wetlands) and site*richness were specified as random effects. For significant interactions, differences in means of one effect were examined while holding the other effect(s) constant. Relationships amongst response variables (potential methane oxidation, potential methane production, soil pH, and SOM) were analyzed separately by Pearson correlations for all combinations of response variables (proc CORR, SAS 9.3).

Results

Wetland type, soil depth, and plant species richness

Wetland type (created versus natural) and soil depth (0-10 cm versus 10-30 cm) were significant effects for potential methane oxidation and potential methane production (Table 1.1). Mean potential methane oxidation was significantly greater in natural wetlands than in created (10.94 and 4.29 ng CH_4-C g^{-1} dry soil h^{-1} respectively; Figure 1.1 A) and significantly greater at 0-10 cm than at 10-30 cm (7.97 and 6.04 ng CH_4-C g^{-1} dry soil h^{-1} respectively; Figure 1.1 B). Likewise, potential methane production was significantly greater in natural wetlands than in created (2.96 and 0.44 ng CH_4-C g^{-1} dry soil h^{-1} respectively; Figure 1.1 C) and significantly greater at 0-10 cm than at 10-30 cm (2.69 and 0.49 ng CH_4-C g^{-1} dry soil h^{-1} respectively; Figure 1.1 D).

By contrast, soil moisture, soil organic matter (SOM), and soil pH had significant interactions with depth (Table 1.1). Soil moisture was significantly higher in natural wetlands than in created at 0-10 cm (316 and 87 % respectively) and 10-30 cm (210 and 67 % respectively; Figure 1.2 A). Soil organic matter was also significantly higher in natural wetlands than in created at 0-10 cm (35 and 11 % respectively) but there were no statistically significant differences due to wetland type at 10-30 cm (Figure 1.2 B). Soil pH was significantly lower in natural wetlands than in created at 0-10 cm (6.14 and 7.16 respectively) and 10-30 cm (6.01 and 7.66 respectively; Figure 1.2 C). There were no differences in soil moisture or soil organic matter with depth in created wetlands, but in natural wetlands soil moisture and soil organic matter were significantly higher at 0-10 cm than at 10-30 cm (Figures 1.2 A and B). By contrast, there were no differences in soil pH with depth in natural wetlands, but pH was significantly lower at 0-10 cm than at 10-30 cm in created wetlands (Figure 1.2 C).

Plant species richness was a marginally significant effect for potential methane production ($P = 0.09$, Figure 3B), but was not a significant factor explaining any of the other soil variables (Table 1.1, Figure 1.3).

Correlations amongst soil variables

Potential methane oxidation and potential methane production were significantly positively correlated with soil moisture and soil organic matter, and significantly negatively correlated with soil pH, when both wetland types and depths were included (Figure 1.4). Soil organic matter, soil moisture, and soil pH were all significantly correlated with each other (Figure 1.5). However, Ballfield did not fit with the other three wetlands when looking at soil organic matter versus soil moisture (Figure 1.5

A) and Calamus did not fit with the other three wetlands when looking at soil organic matter versus soil pH (Figure 1.5 B) and soil moisture versus soil pH (Figure 1.5 C). Soil organic matter was lower than would have been predicted in Ballfield based on the soil moisture, though this was mostly due to three outlier samples with comparatively high soil moisture (Figure 1.5 A). When all wetlands except Calamus were included, soil organic matter and soil moisture declined with increasing soil pH; by contrast, in Calamus soil organic matter and soil moisture increased with increasing pH (Figures 1.5 B and C).

Discussion

I sampled soils at four wetlands (two created, two natural) to look for the effects of wetland type, soil depth, and plant species richness on potential methane oxidation, potential methane production, and environmental soil properties. I hypothesized that soil organic matter and rates of methane oxidation and production would be reduced in created wetland soils compared to natural, that rates of methane oxidation would decrease, and rates of methane production would increase, with soil depth, and that rates of methane oxidation would increase, and rates of methane production would decrease, with increased plant species richness.

As hypothesized I found that soil organic matter and rates of potential methane oxidation and potential methane production were higher in natural wetlands than in created wetlands. These findings are consistent with what many others have found: carbon cycling is slower and carbon storage is lower in created wetlands than natural ones (Ballantine and Schneider 2009, Hossler and Bouchard 2010, Hossler et al. 2011, Moreno-Mateos et al. 2012). At the time of this study the created wetlands were only seven years old, so it is possible that their carbon-related functions could approach those of natural wetlands in time. For example Wolf et al. (2011) showed an age-related trajectory in organic carbon, total nitrogen, soil moisture, and rates of nitrification and denitrification in created wetlands (aged 3 to 10 years) towards levels/rates seen in natural reference wetlands. However, in a longitudinal study over 10 years at a mitigation wetland, Zedler and Callaway (1999) showed no strong directional changes in soil organic matter or total N, and predicted that it would take more than 40 years for total nitrogen to reach levels seen in the reference marshes, while SOM was predicted to level out at 75 % of natural marsh conditions. Using data from 3-8 year old created wetlands, Hossler and Bouchard (2010) predicted that it would take 300-400 years for carbon content and carbon mineralization rates to reach equivalence with natural wetlands. Additionally, in a meta-analysis of 621 wetland sites from around the world, Moreno-Mateos et al. (2012) showed that even 100 years after restoration biogeochemical responses (e.g. storage and cycling of carbon and nitrogen) in restored and created wetlands had recovered only 74% on average relative to the reference wetlands.

Potential methane oxidation and potential methane production also varied significantly with all three environmental soil properties measured (soil moisture, soil organic matter, and soil pH), all of which also varied significantly between created and natural wetlands. Because all three of these properties were highly correlated with each other, it is difficult to say whether any one of them was the primary factor mediating potential methane oxidation and/or potential methane production. However, decreases in pH have been shown to decrease rates of hydrogen production (Goodwin et al. 1998); because hydrogen can couple organic carbon degradation with methane production, I would expect that decreases in pH would be correlated with decreases in methane production. While others have found support for this relationship (Dunfield et al. 1993, Valentine et al. 1994, Ye et al. 2012), I actually found the opposite (soil pH was negatively correlated with potential methane production); therefore it is unlikely that differences in soil pH explain differences in potential methane production. Soil moisture and soil organic matter were more strongly correlated with potential methane production and are therefore much more likely candidates as factors explaining some of the variability. These findings are consistent with what others have found as wetland hydrology (MacDonald et al. 1996, MacDonald et al. 1998, Grünfeld and Brix 1999, Fiedler and Sommer 2000, Freeman et al. 2002, Megonigal and Schlesinger 2002, Rask et al. 2002, Vann and Megonigal 2003) and carbon availability (Crozier et al. 1995, Yavitt 1997, D'Angelo and Reddy 1999, Miller et al. 1999, Fiedler and Sommer 2000, Coles and Yavitt 2002) have repeatedly been shown to mediate methane production in wetlands (For a review see Le Mer and Roger 2001).

Because methane oxidation is dependent on oxygen availability (King 1996, Calhoun and King 1997), the finding that potential methane oxidation was positively correlated with soil moisture in this study was unexpected. However, because the lab incubations were kept oxygenated this was no longer a limiting factor during the incubations. Because methanotrophs are also limited by methane availability (Freeman et al. 2002, Megonigal and Schlesinger 2002), I would expect that increases in methane would lead to increases in methane oxidation. During potential methane oxidation incubations, methane was not a limiting factor as each sample received equal amounts of methane. However, differences in potential methane oxidation between created and natural wetlands suggest that in situ factors mediating methanotrophic activity carried over into the incubations. Therefore, I would expect that conditions that enhance methane production in situ would also enhance methanotrophic activity, assuming that there were areas of the soil that received enough oxygen for methanotrophs to remain active (rhizosphere and oxygenated surface). Thus, the increased soil organic matter and soil moisture in natural wetlands would be expected to not only enhance potential methane production but also potential methane oxidation.

As hypothesized, potential methane oxidation was greater in the top 10 cm than in the 10-30 cm depth. However, contrary to my hypothesis, potential methane production also declined with soil depth. In fact, the magnitude of the change in average rates of methane production from 0-10 to 10-30 cm was greater than that for potential methane oxidation. I believe this to be an effect of conducting controlled laboratory incubations to measure these rates. The primary reason why I expected methane production to increase with depth is because methanogenesis is an anaerobic process and oxygen becomes depleted with depth. However, under the anaerobic conditions of the laboratory incubations, the control on methanogenic activity was most likely carbon availability rather than the presence/absence of oxygen. This is supported by my findings that potential methane production was significantly correlated with soil organic matter, which was lower in the 10-30 cm depth than the 0-10 cm depth.

While others have found that plant species (or functional group) richness (or diversity) can influence plant biomass and nutrient retention in wetlands (Engelhardt and Ritchie 2001, Zedler et al. 2001, Callaway et al. 2003), and there is some support for reduced methane emissions with increasing plant species richness (Bouchard et al. 2007), I did not find any significant relationship between plant species richness and potential methane oxidation, soil moisture, soil pH, or soil organic matter, and only a weak positive relationship with potential methane production. However, the findings reported here do not address plant factors such as community composition that may be more important than species richness. Community composition was considered in the larger project and we found that the composition of the plant community was a better predictor of carbon cycling dynamics than plant diversity (Schultz et al. 2011). In the experimental mesocosm study that followed this field study (Chapter 2 of this dissertation) I also found that the composition of the plant community was more important than richness (Andrews et al. 2013).

In this study rates of potential methane oxidation were greater than rates of potential methane production, suggesting that in situ these wetlands could act as a sink for methane. However, it should be stressed that these are potential rates determined under idealized lab conditions. In fact, we did find that methane was being emitted from these wetlands at the time of sampling (Schultz et al. 2011). One explanation for this is that during the lab incubations methanotrophs were provided with oxygen and methane, removing both of the primary limiting factors to their growth. In contrast, while the methane production incubations were kept anaerobic, I did not amend with any carbon sources so carbon was likely still a limiting factor in these incubations. Thus, while the rates of potential methane oxidation likely represent the maximum potential oxidation, the rates of potential methane production likely do not. Alternatively, or in addition, other factors in the field, particularly plant transport and ebullition, would certainly play a role in mediating methane flux to the atmosphere.

When looking at average methane flux from each of these wetland sites, Schultz (2010) found that Big Island (a created wetland) had the greatest methane flux, followed closely by Ballfield (a natural wetland), though Big Island had a much higher maximum flux than Ballfield. Clover Groff (a created wetland) and Calamus (a natural wetland) had much lower average methane flux than Big Island or Ballfield. Because of this inter-site variability there was no difference in methane emissions between created and natural wetlands. It is interesting that the wetland with the highest soil organic matter and soil moisture (Calamus) and the wetland with the lowest soil organic matter and soil moisture (Clover Groff) had similar average methane flux in situ. Based on my findings I believe that at Clover Groff the low efflux was due to low rates of methane production and at Calamus the low rates were due to high rates of methane oxidation (see Appendix Table A1.1 for average rates by wetland).

In conclusion I found that potential methane oxidation, potential methane production, soil organic matter, and soil moisture were all lower, and soil pH was higher, in created wetlands than in natural wetlands. Differences in rates of potential methane oxidation and potential methane production between created and natural wetlands are most likely explained by differences in soil moisture and soil organic matter content. Despite my findings that rates of potential methane oxidation were greater than rates of potential methane production, Schultz et al. (2011) found that at the time of sampling these sites were showing net methane flux to the atmosphere. In situ processes such as plant transport and ebullition that would allow methane to bypass methanotrophs could explain this.

Table 1.1. Linear mixed effect model F values (num df, den df) for main effects and significant interactions.

Main effects and interactions	PMO	PMP	Soil Moisture	SOM	Soil pH
Type	21.45 (1, 2)*	33.01 (1, 2)*	20.66 (1, 2)*	3.86 (1, 2)	38.38 (1, 2)*
Depth	5.76 (1, 124)*	29.70 (1, 124)***	14.61 (1, 124)***	8.91 (1, 124)**	8.59 (1, 124)**
Type*depth	0.81 (1, 124)	0.18 (1, 124)	6.74 (1, 124)**	4.50 (1, 124)*	26.24 (1, 124)***
Richness	0.02 (1, 61)	2.94 (1, 61)†	0.18 (1, 61)	0.02 (1, 61)	0.00 (1, 61)

Notes: PMO = potential methane oxidation, PMP = potential methane production, SOM = soil organic matter. Type = Created or Natural; Depth = 0-10 cm or 10-30 cm; richness = 0-11 plant species (categorized as continuous); † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

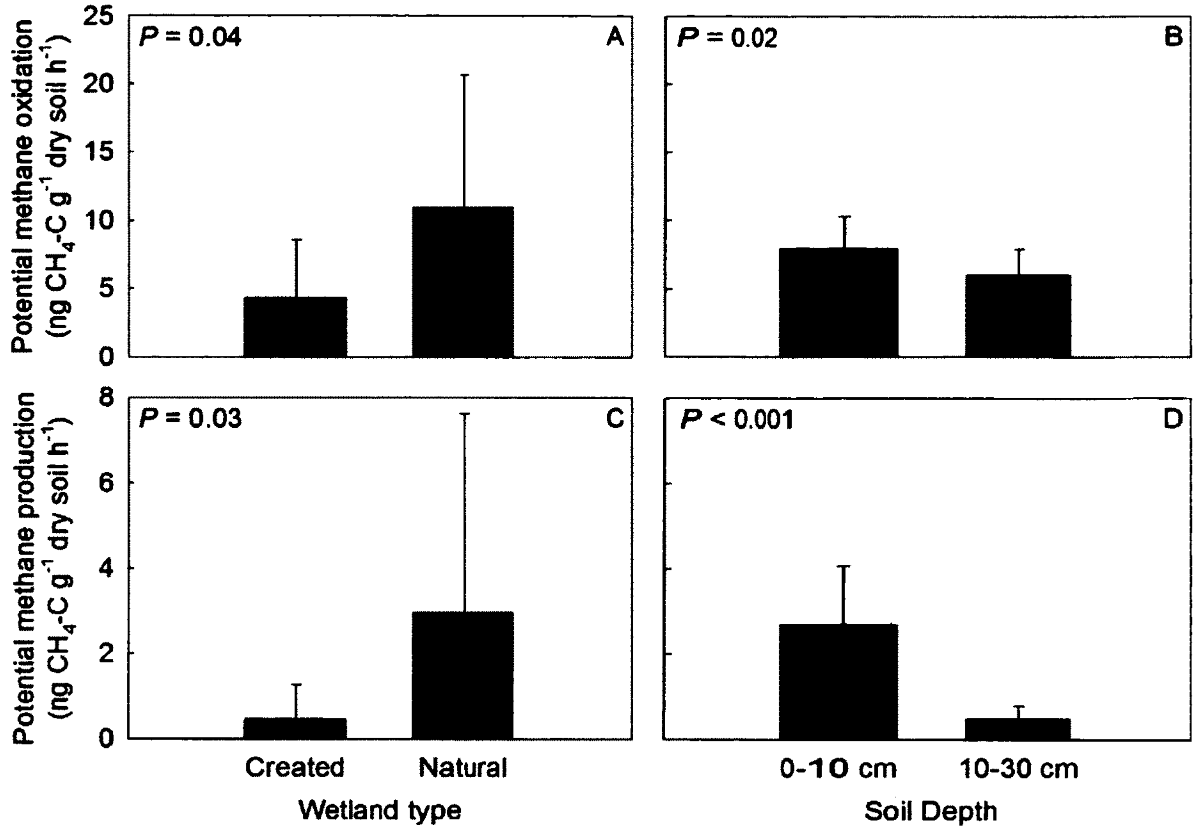

Figure 1.1. The effects of wetland type (left panels) and soil depth (right panels) on potential methane oxidation (top) and potential methane production (bottom). Bars are geometric means with 95% CI.

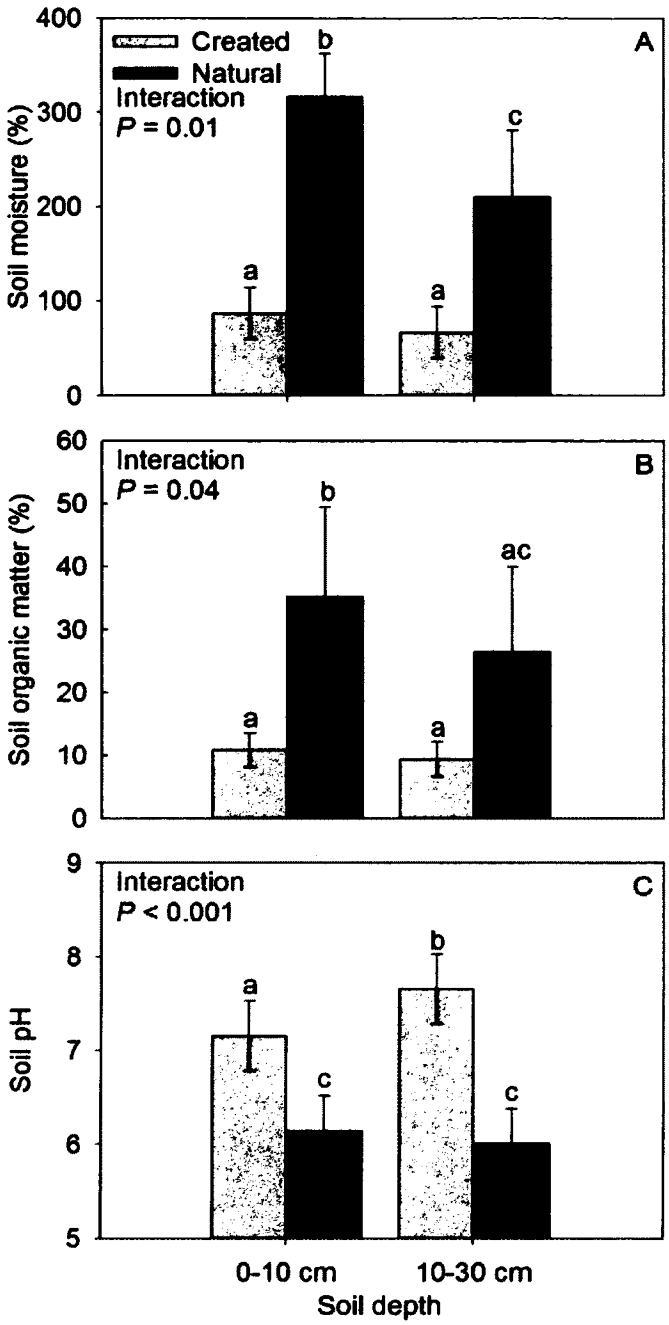

Figure 1.2. The interactive effects of wetland type and soil depth on soil moisture (A), soil organic matter (B), and soil pH (C). Note the y-axis in C does not start at zero. In all panels light bars are created wetlands and dark bars are natural wetlands. Bars are arithmetic means ± 1 SE. Within a panel, bars with different letters are significantly different at $P < 0.05$.

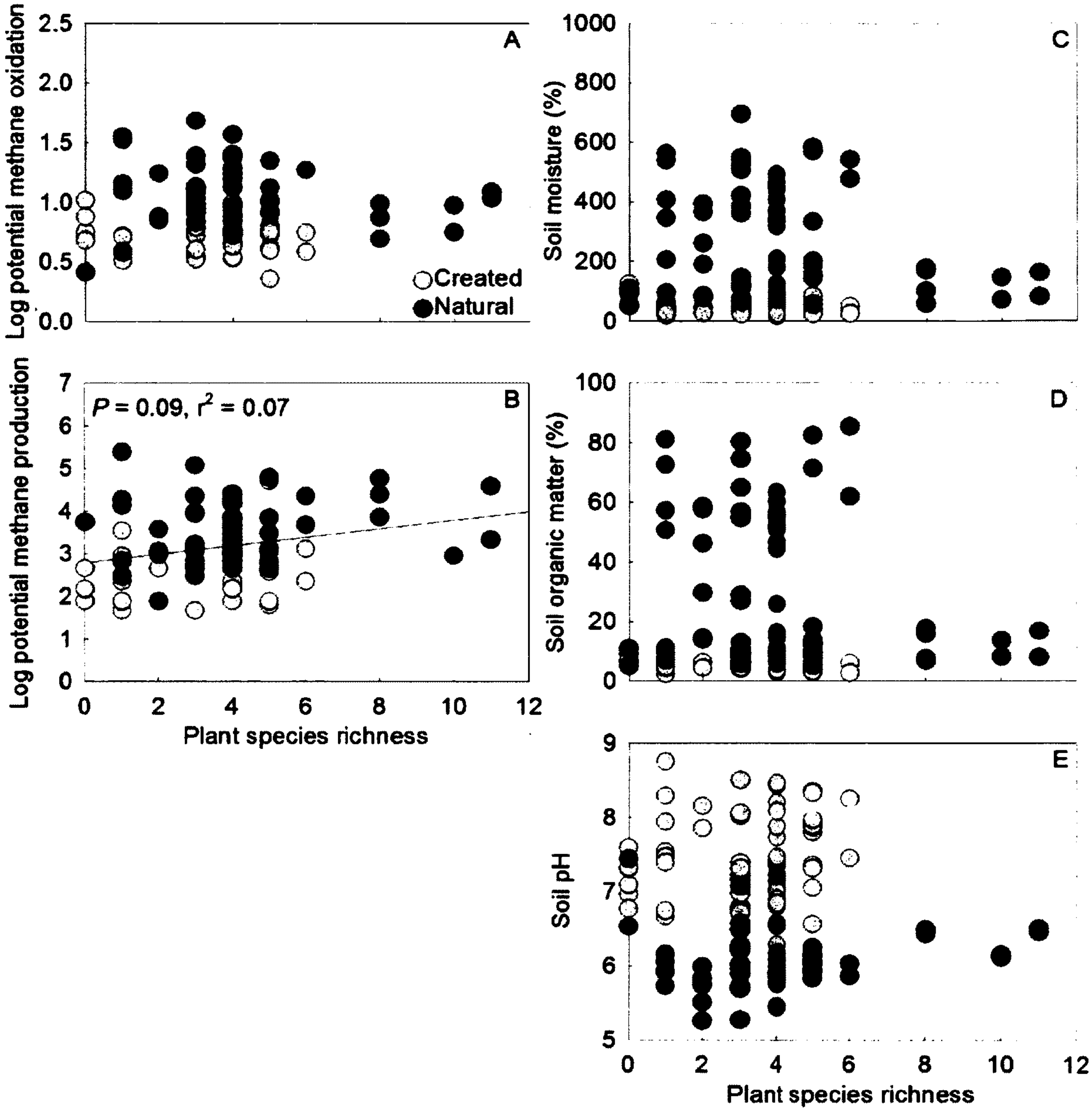

Figure 1.3. Methane (left panels) and environmental soil properties (right panels) as a function of plant species richness. In all panels light symbols are created wetlands and dark symbols are natural wetlands. Both soil depths are included. Original potential methane oxidation (A) and production (B) units were in ng CH_4-C g^{-1} dry soil h^{-1}. Note the y-axis in E does not start at zero.

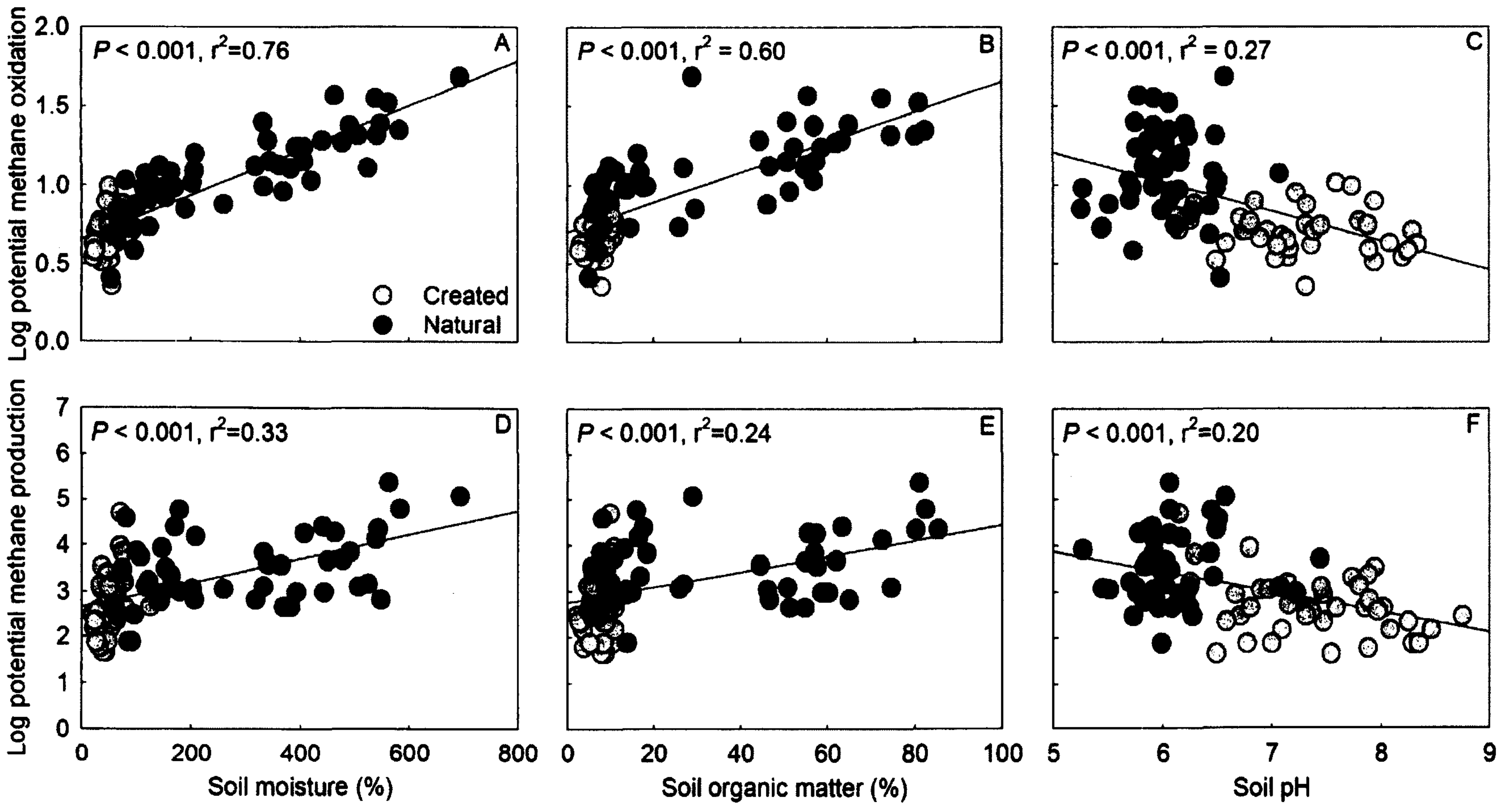

Figure 1.4. Correlations between potential methane oxidation (top panels) or potential methane production (bottom panels) and soil moisture (A and D), soil organic matter (B and E), and soil pH (C and F). Regression lines were fit across all wetlands (both soil depths included). In all panels light symbols are created wetlands and dark symbols are natural wetlands. Original potential methane oxidation and production units were in ng CH_4-C g^{-1} dry soil h^{-1}.

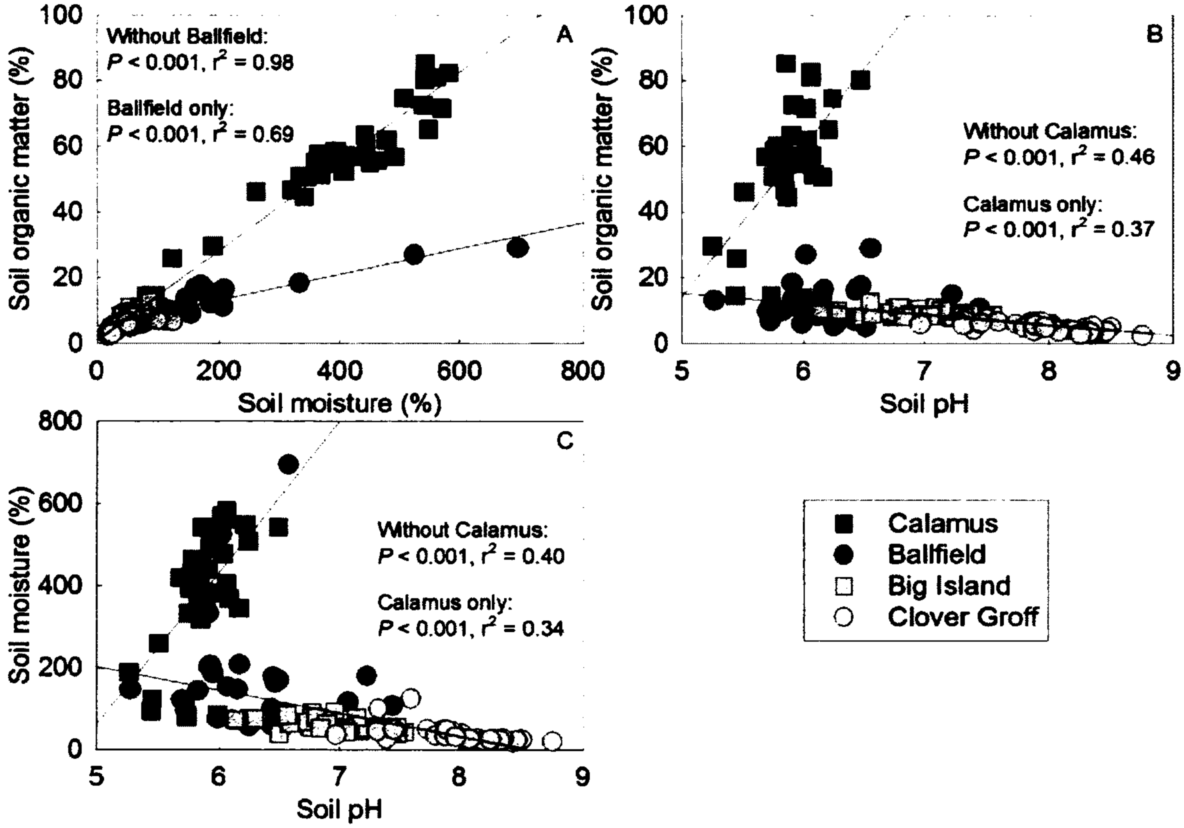

Figure 1.5. Correlations amongst environmental soil properties: soil organic matter versus soil moisture (A), soil organic matter versus soil pH (B), and soil moisture versus soil pH (C). In all panels light symbols are created wetlands and dark symbols are natural wetlands.

CHAPTER 2

PLANT COMMUNITY STRUCTURE MEDIATES POTENTIAL METHANE PRODUCTION AND POTENTIAL IRON REDUCTION IN WETLAND MESOCOSMS*

Abstract

Wetlands are the largest natural source of methane to the atmosphere, but factors controlling methane emissions from wetlands are a major source of uncertainty in greenhouse gas budgets and projections of future climate change. We conducted a controlled outdoor mesocosm experiment to assess the effects of plant community structure (functional group richness and composition) on potential methane production and potential iron reduction in freshwater emergent marshes. Four plant functional groups (facultative annuals, obligate annuals, reeds, and tussocks) were arranged in a full-factorial design and additional mesocosms were assigned as no-plant controls. Soil samples from the top 10 cm were collected three times during the growing season to determine potential methane production and potential iron reduction (in unamended soils and in soils amended with 200 mM formate). These data were compared to soil organic matter, soil pH, and previously published data on above and belowground plant biomass. We found that functional group richness was less important than the presence of specific functional groups (reeds or tussocks) in mediating potential iron reduction. In our mesocosms, where oxidized iron was abundant and electron donors were limiting,

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iron reducing bacteria outcompeted methanogens, keeping methane production barely detectable in unamended lab incubations. When the possibility of re-oxidizing iron was eliminated via anaerobic incubations and the electron donor limitation was removed by adding formate, potential methane production increased and followed the same patterns as potential iron reduction. Our findings suggest that in the absence of abundant oxidized iron and/or the presence of abundant electron donors, wetlands dominated by either reeds or tussocks may have increased methane production compared to wetlands dominated by annuals. Depending on functional traits such as plant transport and rhizospheric oxygenation capacities, this could potentially lead to increased methane emissions in some wetlands. Additional research examining the role these plant functional groups play in other aspects of methane dynamics will be useful given the importance of methane as a greenhouse gas.

Introduction

The structure and function of ecosystems are being greatly altered by human activities (Vitousek et al. 1997), and the resulting loss of species worldwide has led to increasing concern for the consequences of reduced biodiversity across a wide range of ecosystems (Naeem et al. 1994, Chapin et al. 2000, Loreau et al. 2001, Zedler et al. 2001, Hooper et al. 2005, Lovett et al. 2009, Geyer et al. 2011). Freshwater wetland ecosystems provide a number of valuable services, including biodiversity support, water quality maintenance and improvement, flood control, and carbon storage (Zedler and Kercher 2005). While there are a number of studies documenting changes in wetland biodiversity as a consequence of human activities (Findlay and Houlahan 1997, Findlay and Bourdages 2000, Houlahan and Findlay 2004, Rosas et al. 2006, Schooler et al. 2006), there have been fewer studies on links between changes in biodiversity and functions that support wetland services (Engelhardt and Ritchie 2001, Mahaney et al. 2006, Bouchard et al. 2007, Schultz et al. 2011).

Alterations in plant community structure can affect ecosystem functioning because plants differ in their rates and mechanisms of resource utilization and in how they influence other plants and their physical environment (Chapin et al. 2000). Growing research indicates that restored and created wetlands do not exhibit or maintain the same functional or physical characteristics, including plant biomass, plant species richness, and biogeochemical functions, as natural wetlands (Zedler et al. 2001, Hossler et al. 2011, Moreno-Mateos et al. 2012). Thus, it is especially important that we understand the role that plant community structure plays in mediating wetland properties such as methane production and oxidation, organic matter dynamics, and plant biomass (Joabsson et al. 1999, Engelhardt and Ritchie 2001, Vann and Megonigal 2003, Bouchard et al. 2007).

Of the long-lived greenhouse gases, methane is second only to CO_2 in radiative forcing (Forster et al. 2007); because methane is such a potent greenhouse gas, understanding factors that affect methane dynamics is especially important. Wetlands are the single largest natural source of methane to the atmosphere, contributing an estimated 100-231 Tg CH_4 yr^{-1} (Christensen et al. 2003, Shindell 2004, Denman et al. 2007). Freshwater wetlands may account for 20-39% of the total global methane emissions and as much as 90% of natural emissions (Denman et al. 2007). Previous studies have measured highly variable rates of methane production in wetland sediments (Schimel 1995, Whalen and Reeburgh 2000, Krüger et al. 2001, Freeman et al. 2002, Megonigal and Schlesinger 2002, Keller et al. 2005, Welsch and Yavitt 2007, Sutton-Grier and Megonigal 2011) but the controlling factors contributing to this variability are still not well understood. Despite the significance of freshwater wetlands as a source of methane, this continued uncertainty about controls on sediment methane cycling stresses the need for further research of belowground processes. This task is particularly complex in vegetated wetlands due to the number of feedbacks between plants and microbes, the number of transport pathways plants provide, and competition with other microbes for electron donors (see Laanbroek 2010 for a review).

Methane production is performed by methanogenic archaea in the anaerobic zones of wetland sediments, but methanogens face competition for methanogenic substrates (i.e. organic acids for acetoclastic methanogens and hydrogen for hydrogenotrophic methanogens) from bacteria that can utilize more energetically favorable electron acceptors such as sulfate and oxidized iron. Competition with sulfate reducers is more likely to dominate in marine or other sulfate rich wetlands, while in freshwater wetlands competition with iron reducers is more likely (Laanbroek 2010). This competition has been shown to suppress methane production and reduce methane emissions (Roden and Wetzel 1996, van der Nat and Middelburg 1998, Frenzel et al. 1999, Neubauer et al. 2005). Plants contribute to these processes by providing carbon substrates (electron donors) to methanogens and their competitors through root exudation and root turnover and by creating an oxygenated rhizosphere where reduced iron can be re-oxidized and methane can be consumed (Laanbroek 2010).

While there have been studies examining the effects of specific plant species on methane dynamics (Chanton et al. 1993, Calhoun and King 1997, Ström et al. 2005, Smialek et al. 2006, Welsch and Yavitt 2007), including studies looking at suppression by iron reducers (Roden and Wetzel 1996, Frenzel et al. 1999, Neubauer et al. 2005, Sutton-Grier and Megonigal 2011), there has been very little work looking at the effects of plant community structure on methane or iron cycling. As part of a larger project, our overall objective was to explore the interactions between plant community structure and belowground processes in the context of experimental freshwater wetland mesocosms. Here we focus specifically on the effects of plant community structure (functional group richness and composition) on potential methane production and potential iron reduction. We chose to utilize functional groups (facultative annuals, obligate annuals, reeds, and tussocks) rather than individual species in order to account for redundancy among species with similar functional traits.

Previous findings suggest that belowground biomass can increase with functional group richness (the number of functional groups present) as plants from different functional groups penetrate different niches (Bouchard et al. 2007). Increases in belowground biomass should lead to greater root turnover and root exudates, which contribute to the pool of available carbon substrates for methanogens and iron reducing bacteria. With that in mind, we chose functional groups that differ in their belowground biomass and morphology: facultative and obligate annuals tend to have shallow roots and lower root biomass than the reeds and tussocks, which typically have increased root biomass, penetrate more deeply and exhibit lateral spreading (Boutin and Keddy 1993). We hypothesized that potential methane production and potential iron reduction would be positively correlated with (1) increases in belowground plant biomass, (2) increases in plant functional group richness, and (3) the presence of reeds and/or tussocks.

Materials and Methods

Site description and experimental design

We tested our hypotheses using outdoor experimental wetland mesocosms that allowed us to manipulate the number and composition of functional groups present in the plant community. The mesocosms (130 cm length x 86 cm width x 40 cm depth) were located at the Waterman Agricultural and Natural Resources Laboratory on the main campus of Ohio State University. All mesocosms were filled with low organic matter soil (50/50 silt and sand mix, 3% C, 0.03% N, 2.6% Fe) to minimize the effects of existing organic matter stocks on carbon and nutrient cycling. Four plant functional groups (facultative annuals, obligate annuals, reeds, and tussocks) were chosen to represent a range of plants known to associate closely in freshwater emergent marshes, and were defined based on physiological, morphological, and life history traits (Boutin and Keddy 1993). The functional groups were arranged in a full-factorial design, giving 16 levels of functional group composition (one with no-plants, four with single functional groups, six with two functional groups, four with three functional groups, and one with all four functional groups); each level was randomly assigned to five mesocosms. Throughout the paper we refer to these by capital letter designations: C (no-plant control), F (facultative annuals), O (obligate annuals), R (reeds), and T (tussocks). When more than one functional group is present, they are designated by the combination of letters. For example, FT indicates a community with both facultative annuals and tussocks. These treatments also gave us the ability to look at five levels of functional group richness (number (0-4) of functional groups present) and the presence/absence of each functional group (denoted by italicized capital letters). Plantings (18-20 plants per mesocosm) occurred in June 2006, with each functional group represented by four species (Appendix Table A2.1). A drip irrigation system was installed to keep the mesocosms flooded during the growing season and the mesocosms were irrigated every three days to keep the water level at 10 cm above the soil surface. Further details on the site and experimental design are reported in Schultz et al. (2012).

Plant sampling and analysis

Details on plant sampling are reported in Schultz et al. (2012). Briefly, destructive sampling for root and shoot biomass was conducted at peak biomass (Sept. 1st and 2nd) in 2008 from one half of each mesocosm. All stems were clipped down to the soil surface and plants were sorted for each plot by species and placed in paper bags and dried.

Immediately after aboveground samples were collected, two soil cores (7 cm diameter, 10 cm depth) were collected from each mesocosm and bulked for analysis of root biomass. Soil cores for root biomass were washed with a Delta-T Root Washer (500 μm mesh filter) followed by a 1 mm sieve and stored at -10°C until analysis. Live roots were then manually sorted from detritus. Root and shoot samples were oven dried for 72 hours at 55°C to constant mass. Subsamples of dried roots and shoots were then combusted in a muffle oven at 450°C for 8 hours to determine the ash-free dry weight.

Soil sampling and analysis

Soil samples were collected in June, August, and November 2008. Because these were young systems (only 2 years old) we expected to see stronger effects of plants close to the soil surface (top 10 cm) where most of the root growth was occurring (root biomass increased by 219% in the top 10 cm from 2007 to 2008 but only by 33% below 10 cm; Schultz, 2010). Therefore, because logistical constraints limited our ability to look at multiple depths, we chose to use the top 10 cm of soil. It should be noted however that due to this approach we may have missed treatment effects of root distribution on potential methane production and potential iron reduction. Surface water was temporarily drained and three soil cores (2 cm diameter) were collected from each mesocosm and bulked for analysis. Soil samples were immediately double bagged in re-sealable plastic zipper bags (to minimize oxygen infiltration), homogenized, and shipped overnight to the University of New Hampshire, where they were stored at 4°C until analysis.

Sub-samples were used to estimate potential methane production and potential iron reduction and to measure soil moisture, soil organic matter (SOM), and pH. Soil moisture was determined by drying subsamples at 105°C to constant mass. The dried soils were then combusted in a muffle oven at 450°C for 6 hours to determine organic matter by loss-on-ignition. The compact nature of the soils and the high concentration of fine roots made it difficult to remove all roots from the samples; as a consequence the SOM results may include some fine root biomass. Soil pH was determined on 1:2 soils : deionized water slurries.

Potential methane production and potential iron reduction

Early trial incubations in unamended soils (only water added) yielded very low (often undetectable) rates of potential methane production and so we chose to test a variety of carbon substrate amendments utilized by both methanogens and iron reducers (acetate, formate, and an H_2-CO_2 gas mix). In these test runs, potential methane production and potential iron reduction did not differ significantly between acetate amended soils and unamended soils, nor between formate amended soils and H_2-CO_2 amended soils (S.E. Andrews, *unpublished data*). Therefore, due to time and space constraints, we chose to use formate as the carbon substrate amendment for all subsequent incubations. For potential methane production, soils (1 g wet weight ± 0.1 g) were loaded into 20 mL clear serum vials inside an anaerobic N_2 filled chamber. Vials were capped with red rubber septa and sealed prior to removal from the chamber. Vials were then flushed with ultrapure N_2 for 2 min to ensure anaerobic conditions and were incubated overnight at 25°C. The following day, 2 mL of either water (unamended) or 200 mM formate (amended) were injected through the septa, and vials were vortexed for 30 seconds and incubated for 10 days at 25°C. Vials were flushed with N_2 gas for 2 min twice within the first 3 days of the incubation to ensure that anaerobic conditions were being maintained. Four headspace samples were taken starting at 72 hours after the last flush (day 6): vials were vortexed for 30 seconds before the entire headspace was evacuated into 60 mL syringes (used to create a strong enough vacuum to pull the bulk of the headspace from the vials). Immediately after sampling, vials were re-flushed with ultrapure N_2 for 2 min to maintain pressure and anaerobic conditions. Headspace samples were stored in evacuated 20 mL clear serum vials at room temperature until the contents could be analyzed for methane concentration (within 24 hours of headspace sample collection). Triplicate blanks (3 mL deionized water) were treated and sampled identically to the soil samples. Methane samples were analyzed using a gas chromatograph equipped with a flame ionization detector (Shimadzu GC-8A) and a 1-mL sample loop. The carrier gas was N_2 with a flow of 30 mL/min. Standardization was done using a calibrated breathing air cylinder based on NOAA ESRL standards. Linear regression analysis (PROC REG, SAS 9.3) was used to calculate the rate of methane produced over time. Rates were accepted for lines with $r^2 \geq 0.75$ and $P \leq 0.05$ (95% of rates met these criteria); rates that did not meet these criteria were not accepted and were treated as missing data.

Incubations for potential iron reduction were conducted on soils collected in August and November of 2008. To determine potential iron reduction, Fe(II) concentrations were measured twice: once on unamended soil samples that were destructively sampled prior to the incubation (treated exactly as those for potential methane production except all vials received only 2 mL of water, Fe(II) was determined immediately after vials were vortexed on the first day, and soils were subsequently discarded) and once on the soil samples that were used to measure potential methane production (both the amended and unamended soils were destructively sampled after the last methane headspace sample was taken). Potential iron reduction rates were then determined by subtracting the initial Fe(II) concentration from the final Fe(II) concentration and dividing by the length of the incubation (the Fe(II) determined on unamended soils destructively sampled prior to incubation was used as the initial Fe(II) concentration for both the amended and unamended incubated soils). While we were unable to measure Fe(II) at more than two sampling times, others have found linear increases in iron reduction within the first three to twenty days of incubation (Roden and Wetzel 1996, Frenzel et al. 1999, and Roden and Wetzel 2003). We cannot rule out the possibility that our rates might not be linear but our rates do reflect the total accumulated iron reduced during our incubation and thus do not limit our ability to make comparisons across the treatments.

The method used to determine reduced iron content was modified from methods used by others (Sørensen 1982, Lovley and Phillips 1987, Achtnich et al. 1995) so that samples could be analyzed using a microplate reader. Briefly, vials were shaken and 0.3 mL of slurry was incubated with 5 mL of 0.5 M HCl for one hour at room temperature to dissolve poorly crystalline iron. After incubation, the slurry-HCl mix was shaken and 0.1 mL was added to 1 mL of Ferrozine reagent (1 g Ferrozine in 1000 mL of 50 mM HEPES buffer) in 2 mL amber microcentrifuge tubes. Tubes were centrifuged at 10,000 g for 2 minutes (Beckman Coulter Microfuge® Centrifuge) and then samples were pipetted into microplates (clear, flat-bottomed, 96 well, 350 µl well volume). Absorbance at 562 nm was measured immediately on a microplate reader (BioTek Synergy HT) using Gen5 software (2005). Triplicate blanks (deionized water) were treated identically to the soil samples. Initial and final Fe(II) concentrations were determined using standards made from ferrous ammonium sulfate.

Statistical analyses

To test for the effects of functional group richness, functional group composition, and presence/absence of functional groups, separate linear mixed effects models (LME) were done with either potential methane production or potential iron reduction as the dependent variable (PROC MIXED, SAS 9.3). All data were log transformed to adjust for heteroscedasticity and non-normality. We used LME for several reasons. First, LME are less sensitive to missing observations than ANOVA (SAS Institute Inc. 2008) and the 5% of our potential methane production rates that did not satisfy our criteria for acceptance ($r^2 \geq 0.75$, $P \leq 0.05$) were treated as missing observations. Second, our design includes a repeated measure (month) on each mesocosm (a random effect), which gives rise to correlated errors. By using LME we could model an appropriate covariance structure to account for correlated errors (Littell et al. 2006). Finally, we also have a split-plot factor (amended versus unamended) that gives rise to multiple sources of random error. In SAS, ANOVAs (proc GLM) incorrectly compute standard errors for interactions in split-plot experiments and cannot complete a correct analysis; therefore LME are recommended (Littell et al. 2006).

For all models a factorial analysis of the fixed effects was performed, where the whole-plot factor was functional group richness (0-4), functional group composition (16 levels), or presence/absence of functional groups (factorial of *F*, *O*, *R*, and *T*; coded as present or absent), the repeated measure was month (June, August, and November for methane and August and November for iron), the split-plot factor was substrate (amended or unamended), and mesocosm was specified as a random effect (nested in the whole-plot factor). For the presence/absence models the no-plant controls were removed from analysis and only two-way interactions amongst *F*, *O*, *R*, and *T* were included. Including the higher-order interactions in the models resulted in parameter instability that in some cases led to least square means estimates outside of the data range. While there were a few statistically significant three-way interactions in earlier models, these were not biologically meaningful nor did they explain anything that could not already be seen from the two-way interactions. Similar presence/absence models were run with root biomass or shoot biomass as the dependent variable (see Schultz et al. 2012 for the effects of functional group richness and composition on plant biomass) but neither substrate nor month was included in those models as they were not applicable. Models were also run using pH or soil organic matter (SOM) as dependent variables; substrate was not included in these models as pH and SOM were measured prior to amendment.

Models were left in their full form because we were more interested in exploring significant effects than parsing down to predictive models at this stage. Where main effects were significant, differences in least squares means were assessed using Tukey's test of multiple comparisons. For significant interactions, differences in means of one effect were examined while holding the other effect(s) constant. Relationships amongst response variables (potential methane production, potential iron reduction, root biomass, shoot biomass, soil pH, and SOM) were analyzed separately by Pearson correlations for all combinations of response variables (proc CORR, SAS 9.3).

Results

Potential methane production and potential iron reduction

Potential methane production and potential iron reduction were significantly higher in amended soils than unamended for all sampling months (Figure 2.1). For potential methane production there was a significant interaction between month and substrate (Table 2.1): for unamended soils there were no significant differences in potential methane production amongst months (< 0.07 ng CH_4-C·g^{-1}·dry soil·h^{-1}), but soils amended with formate had significantly higher potential methane production in June (0.43 ng CH_4-C·g^{-1} dry soil·h^{-1}) than in August or November (0.29 and 0.25 ng CH_4-C·g^{-1} dry soil·h^{-1} respectively; Figure 2.1 A). There was no month*substrate interaction for potential iron reduction (Table 2.1): regardless of substrate addition, potential iron reduction was significantly higher in August than in November (13.16 µg Fe(II)·g^{-1} dry soil·h^{-1} and 8.17 µg Fe(II)·g^{-1} dry soil·h^{-1} respectively; note that data in Figure 2.1 B is shown by month and substrate so that differences can be more easily visualized).

There were no significant interactions between month and functional group richness or month and functional group composition for either potential methane production or potential iron reduction (data not shown). The lack of significant interactions indicates that even though rates decreased with month (Figure 2.1), the patterns remained the same (data not shown). Therefore, for the remaining results, data from all sampling months were combined.

Functional group richness and composition

Potential methane production in unamended soils did not vary with functional group richness, however, potential methane production in amended soils was lowest (0.08 ng CH_4-C·g^{-1} dry soil·h^{-1}) in the no-plant controls and highest (0.62 ng CH_4-C·g^{-1} dry soil·h^{-1}) when all four functional groups were present (Figure 2.2 A; FGR*substrate interaction in Table 2.1). For unamended and amended soils potential iron reduction was also lowest (2.35 and 6.74 µg Fe(II)·g^{-1} dry soil·h^{-1}, respectively) in the no-plant controls and highest (7.74 and 22.00 µg Fe(II)·g^{-1} dry soil·h^{-1}, respectively) when all four functional groups were present (Figure 2.2 C). While functional group richness was a significant effect for both potential methane production (amended only) and potential iron reduction (amended and unamended; Table 2.1), the only significant differences amongst treatment levels were between the no-plant controls and the vegetated treatments (0 and 1-4 respectively, Figures 2.2 A and C). Soil pH and SOM showed similar patterns (though pH in the no-plant controls was higher than other levels of richness rather than lower; Table 2.1 and Figures 2.2 B and D); however, the models for pH and SOM were not significantly better than the null models (i.e. models without fixed effects) and so we cannot say that there were truly differences in pH or SOM with the treatments. This is most likely due to the very narrow ranges over which pH and SOM varied (Appendix Table A2.2).

While potential methane production (amended only) and potential iron reduction (unamended and amended) varied amongst the 16 levels of plant community composition (Appendix Table A2.3), and functional group composition was a significant effect (Table 2.1), the only significant findings for vegetated treatments were that potential methane production in amended soils was significantly lower in the O treatment (0.14 ng CH_4-C·g^{-1} dry soil·h^{-1}) than in the T, FOR, and FORT treatments (0.49, 0.52, and 0.62 ng CH_4-C·g^{-1} dry soil·h^{-1} respectively), while potential iron reduction in the amended soils was significantly lower in the O and F treatments (8.88 and 9.23 µg Fe(II)·g^{-1} dry soil·h^{-1} respectively) than in the OR treatment (26.94 µg Fe(II)·g^{-1} dry soil·h^{-1}, Appendix Table A2.3). Potential iron reduction in unamended soils did not vary significantly with functional group composition; however, the trends were the same as for the amended soils (Appendix Table A2.3).

When looking at the presence of each of the four functional groups compared to their absence, a more significant pattern emerged: potential methane production (amended only) and potential iron reduction (amended and unamended) were enhanced when either reeds or tussocks were present compared to when they were both absent (Figure 2.3). In the absence of reeds potential methane production (amended only) and potential iron reduction were higher when tussocks were present compared to absent (though not significant for unamended potential iron reduction). Similarly, when tussocks were absent, potential methane production (amended only) and potential iron reduction (amended and unamended) were higher when reeds were present compared to absent. However, when reeds and tussocks were present together, neither potential methane production nor potential iron reduction was greater than when reeds were present without tussocks or when tussocks were present without reeds. The presence of reeds and tussocks together did result in significantly greater potential iron reduction (amended and unamended) than the absence of both (Figures 2.3 C and

D), but potential methane production was not significantly greater when both reeds and tussocks were present than when both were absent (Figure 2.3 B). Root and shoot biomass were also significantly greater in the presence of reeds and/or tussocks compared to the absence of both (Figure 2.4 and Appendix Table A2.4).

Relationships amongst soil and plant properties

Potential methane production was positively correlated with potential iron reduction in amended and unamended soils (Table 2.2). Potential methane production (amended only) and potential iron reduction (amended and unamended) were positively correlated with root and shoot biomass (Table 2.2). Soil organic matter (SOM) remained low (1.6 to 2.4 %) and soil pH remained slightly alkaline (7.7 to 8.0) throughout the experiment (Appendix Table A2.2). Despite the narrow range over which SOM and pH varied, potential methane production (amended only) was significantly correlated with pH (negatively) and SOM (positively). Soil organic matter was also positively correlated with both root and shoot biomass, and pH was negatively correlated with SOM and root biomass but not shoot biomass. There were no significant correlations between potential iron reduction and pH or SOM (Table 2.2).

Discussion

We manipulated freshwater wetland plant functional groups in controlled outdoor mesocosms to study the effects of plant community structure on potential methane production and potential iron reduction. We hypothesized that potential methane production and potential iron reduction would increase with belowground biomass and that factors we expected would lead to increased belowground biomass (functional group richness and presence of reeds and/or tussocks) would also be correlated with increases in potential methane production and potential iron reduction.

We found that the plant community had a significant effect on microbial activity, but this effect was primarily on potential iron reduction. In unamended soils, where plant effects were not masked by the addition of a carbon substrate, we found a significant positive correlation between potential iron reduction and plant biomass (root and shoot), significant increases in potential iron reduction in vegetated treatments compared to the no-plant controls, and significantly higher potential iron reduction in the presence of reeds or both tussocks and reeds together compared to the absence of both, lending partial support to all of our hypotheses. We found these same patterns in amended soils (potential iron reduction and potential methane production), suggesting that the effects of plants on microbial activity were not masked entirely by the formate amendment.

Several studies have shown an inverse relationship between plant biomass and methane emissions from wetlands, which is often attributed to increased rhizospheric oxygenation and methane consumption with increasing biomass (Ström et al. 2005, Bouchard et al. 2007, Kao-Kniffin et al. 2010, Koelbener et al. 2010). Our finding that iron reduction was occurring in unamended soils while potential methane production remained barely detectable suggests that another possible explanation for this inverse relationship may be that competition from iron reducing bacteria can inhibit methane production. Iron reducing bacteria have been shown to have lower threshold concentrations for electron donors that are also utilized by methanogens (i.e. organic acids and hydrogen; Lovley 1985, Achtnich et al. 1995, Roden and Wetzel 2003). Therefore, in the presence of oxidized iron, iron reducing bacteria can out-compete methanogens by maintaining the concentration of electron donors at levels too low for methanogens to metabolize (Roden and Wetzel 1996, Frenzel et al. 1999, and Neubauer et al. 2005). If plant biomass positively affects iron reducing bacteria, as our positive correlation between plant biomass and potential iron reduction in unamended soils suggests, then in wetlands where oxidized iron is readily available an inverse relationship between plant biomass and methane emissions could be attributed to this competition from iron reducing bacteria. However, Achtnich et al. (1995) found that excess oxidized iron inhibited methanogenesis, but only if the concentration of electron donors were limiting in the soil. Because SOM was low (~2%) in our soils (we started with low OM soil to minimize the effects of existing SOM stocks on carbon and nutrient cycling) and our systems were young (2 years), our soils were likely limited in electron donor availability. This is supported by our finding that potential methane production and potential iron reduction were both enhanced substantially in soils amended with formate compared to unamended soils.

In addition to providing carbon substrates to iron reducing bacteria, plants have been shown to positively influence iron reduction by creating an oxygenated rhizosphere where reduced iron can be re-oxidized (Roden and Wetzel 1996, Neubauer et al. 2005). Whether re-oxidation of iron in the rhizosphere was a factor limiting methane production in our soils is difficult to determine for two reasons. First, our starting soils contained high levels of total iron (25,000 mg Fe/kg soil) and the water used to flood our mesocosms likely brought in additional iron (total iron increased to an average of 27,000 mg Fe/kg soil after 18 months of flooding; Schultz 2010). This external source of iron may have masked any effects due to internal cycling of iron. Secondly, if re-oxidation was an important limitation on methane production in situ, we would expect to see an increase in methane production in the lab when re-oxidation of iron was prevented via anaerobic incubations. However, while we did see this in our amended soils (where electron donors were not limiting), this was not the case for our unamended soils. This is most likely due to low electron donor availability in conjunction with the high oxidized iron availability in our unamended soils. In our short incubations (10 days), and in situ where we were unable to detect methane emissions, iron reducing bacteria were likely unable to draw down the oxidized iron far enough for methanogens to compete successfully for the electron donors (though we cannot say for sure because we were only able to measure reduced iron at two sampling points). In the lab, our amended incubations removed the electron donor limitation, allowing methanogenic activity to increase to the point where patterns were detectable.

As reported in Schultz et al. (2012), the belowground biomass in these mesocosms increased significantly with functional group richness ($1 < 2 = 3 < 4$). However, while we did find significant positive relationships between functional group richness and potential methane production (amended only) and functional group richness and potential iron reduction (amended and unamended), the only significant differences were between the no-plant controls and the planted treatments, which does not fully support our second hypothesis. This suggests that the presence of vegetation was more important than plant functional group richness in mediating potential methane production and potential iron reduction. However, looking at richness masks differences among treatments in plant community composition within the same level of richness: knowing which functional groups are present is more important in this case than the number of functional groups present. When looking at the presence/absence of functional groups, we found that in vegetated mesocosms reeds and tussocks had the most influence on potential methane production and potential iron reduction: potential methane production (amended only) and potential iron reduction (amended and unamended) were significantly enhanced in the presence of reeds or tussocks (supporting our third hypothesis). Our findings suggest that this increased potential methane production and potential iron reduction is most likely due to higher root biomass and SOM, and therefore enhanced carbon substrate availability, in the treatments containing reeds or tussocks compared to treatments containing only annuals. However, we cannot rule out the possibility that litter chemistry might have played a role. For example, Williams and Yavitt (2010) also found reduced methane production in the presence of a facultative annual (*Lythrum salicaria*) compared to a reed (*Juncus effusus*) or a tussock (*Carex lacustris*), which they attributed to variation in biochemical composition of plant litter.

Studies have shown that increases in root exudates (Koelbener et al. 2010) and methane production (van der Nat and Middelburg 1998) are positively correlated with methane emissions. Therefore, if wetland systems dominated by reeds and/or tussocks have increased methane production (due to increased quantity and/or quality of root exudates and litter) this suggests that they might also have increased methane emissions compared to wetlands dominated by annuals. However, some research has shown that methane emissions are controlled more by differences in rhizospheric oxygenation or plant transport of methane than by root exudates or methane production. For example, Schimel (1995) found that total methane production was not a good predictor of actual emissions; instead, emissions were controlled primarily by the composition of the plant community and its ability to transport methane. Additionally, Ström et al. (2005) found that despite increased carbon substrate availability (acetate) under *Eriophorum vaginatum* or *Juncus effusus*, methane emissions were reduced compared to areas dominated by *Carex rostrata*, which they attributed to the high rhizospheric oxygenation exhibited by *E. vaginatum* and *J. effusus*.

Because of this continued uncertainty surrounding the factors that contribute most toward methane emissions, we cannot infer whether wetlands dominated by reeds or tussocks would have greater emissions that those dominated by annuals based on potential methane production rates alone. However, a recent study looking at the influence of plant functional types on methane emissions (Kao-Kniffin et al. 2010) found no methane emissions from forb treatments (similar in species composition to our facultative annuals) and variable emissions (intermediate to high) from their tussock treatments (similar in species combination to our reeds and tussocks combined). They attributed these differences in emissions to differences in plant productivity, plant transport of methane to the atmosphere, and rhizospheric oxygenation. Their findings lend support to the hypothesis that methane emissions may be enhanced in wetlands dominated by reeds or tussocks compared to those dominated by annuals.

Finally, while we planted four different functional groups as defined by Boutin and Keddy (1993), with respect to potential methane production and potential iron reduction we didn't find any functional differences between the facultative and obligate annuals or between the reeds and tussocks. This suggests that for methane production and iron reduction we functionally only had two groups: annuals and perennials. However, the same may not be true for other aspects of methane and iron dynamics such as gas transport or rhizospheric oxygenation capacity. As methane emissions are controlled by the combination of such factors, future research examining the role of functional groups on methane and iron dynamics in wetlands should consider additional plant traits in determining which functional groups to use (for example, internal gas flow mechanisms, or other traits that mediate gas transport, and quantity/quality of plant litter and root exudates).

In conclusion, we found that the presence of vegetation (compared to no-plant controls), increases in plant biomass, and the presence of reeds or tussocks (compared to mesocosms containing only annuals) led to increased potential iron reduction in amended and unamended soils. In our mesocosms, where oxidized iron was abundant and electron donors were limiting, iron reducing bacteria out-competed methanogens, keeping potential methane production barely detectable in unamended lab incubations and preventing in situ methane emissions. This inhibition of methanogenesis by iron reducing bacteria adds to a growing body of research highlighting the importance of considering the influence of microbes that utilize alternative electron acceptors when studying methane dynamics in wetlands. When the possibility of re-oxidizing iron was eliminated (anaerobic incubations) and the electron donor limitation was removed (amending with formate), potential methane production increased and followed the same patterns as potential iron reduction. Taken together these findings suggest that in systems where oxidized iron availability is high (due to large pools of oxidized iron or rapid cycling of iron), particularly in wetlands where electron donors are limiting, competition with iron reducing bacteria may be an important control on methane emissions. In the absence of abundant oxidized iron and/or the presence of abundant electron donors wetlands dominated by reeds or tussocks may have increased methane production, and, depending on functional traits such as plant transport and rhizospheric oxygenation capacities, this may lead to increased methane emissions in certain wetlands. Additional research examining the role these plant functional groups play in other aspects of methane dynamics, particularly plant transport and rhizospheric oxygenation, will be useful given the importance of methane as a greenhouse gas.

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Table 2.1. Linear mixed effect model F values (num df, den df) for main effects and significant interactions from functional group richness (FGR), functional group composition (FGC), and presence/absence (italicized) models for soil response variables.

Main effects and interactions	PMP	PIR	pH	SOM
FGR	4.88 (4,71)**	6.25 (4, 74)***	5.80 (4, 75)***	4.98 (4, 74)***
Month	0.95 (2, 276)	20.93 (1, 147)***	62.34 (2, 149)***	1.43 (2, 147)
Substrate	256.10 (1, 69)***	336.49 1, 70)***	na	na
FGR*substrate	4.29 (4, 70)**	1.98 (4, 71)	na	na
Month*substrate	11.59 (2, 276)***	1.16 (1, 147)	na	na
FGC	3.64 (15, 61)***	3.97 (15, 64)***	3.39 (15, 65)***	2.81 (15, 62)**
Month	1.33 (2, 237)	44.63 (1, 128)***	95.26 (2, 128)***	6.42 (2, 124)**
Substrate	470.77 (1, 61)***	573.85 (1, 61)***	na	na
FGC*substrate	2.09 (15, 61)*	1.17 (15, 61)	na	na
Month*substrate	13.66 (2, 237)***	1.16 (1, 128)	na	na
F	0.16 (1, 62)	0.68 (1, 64)	0.02 (1, 65)	1.99 (1, 62)
O	1.31 (1, 63)	1.05 (1, 64)	0.27 (1, 65)	0.08 (1, 62)
R	4.81 (1, 63)*	13.42 (1, 64)***	8.16 (1, 64)**	9.98 (1, 61)**
T	1.12 (1, 63)	4.09 (1, 64)*	0.74 (1, 65)	0.00 (1, 62)
*R*T*	9.55 (1, 61)**	5.19 (1, 64)*	3.72 (1, 65)	3.19 (1, 61)
Month	1.12 (2, 237)	31.45 (1, 127)***	85.19 (2, 127)***	4.11 (2, 124)*
Substrate	442.57 (1, 61)***	454.43 (1, 61)***	na	na
*R*T**substrate	4.47 (1, 60)*	4.59 (1, 61)*	na	na
Month*substrate	11.22 (2, 237)***	0.90 (1, 127)	na	na

Notes: PMP = potential methane production, PIR = potential iron reduction, SOM = soil organic matter, *F* = presence/absence of facultative annuals, *O* = presence/absence of obligate annuals, *R* = presence/absence of reeds, and *T* = presence/absence of tussocks. Month = June, August, and November 2008 for PMP, SOM, and pH and August and November 2008 for PIR. Substrate = unamended (water only) versus amended (200 mM formate). SOM and pH were determined prior to amendment. For SOM and pH the fitted models are not better than the null models. na = not applicable, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 2.2. Correlation coefficients for relationships amongst soil and plant response variables.

	PIR-U	PIR-A	pH	SOM	Root Biomass	Shoot Biomass
PMP-U	0.26**		0.18	0.15	0.13	0.10
PMP-A		0.47***	-0.32***	0.32***	0.41***	0.41***
PIR-U			-0.11	0.15	0.23*	0.24*
PIR-A			-0.05	0.12	0.47***	0.36**
pH				-0.28***	-0.46***	-0.12
SOM					0.28*	0.24*

Notes: PMP = log transformed potential methane production; PIR = log transformed potential iron reduction; U = unamended and A = amended with 200 mM formate; SOM = soil organic matter. Correlations amongst PMP, pH, and SOM include June, August, and November 2008; correlations amongst PIR, pH, and SOM include August and November 2008; correlations with root and shoot biomass include only August 2008. *P < 0.05, **P < 0.01, ***P < 0.001.

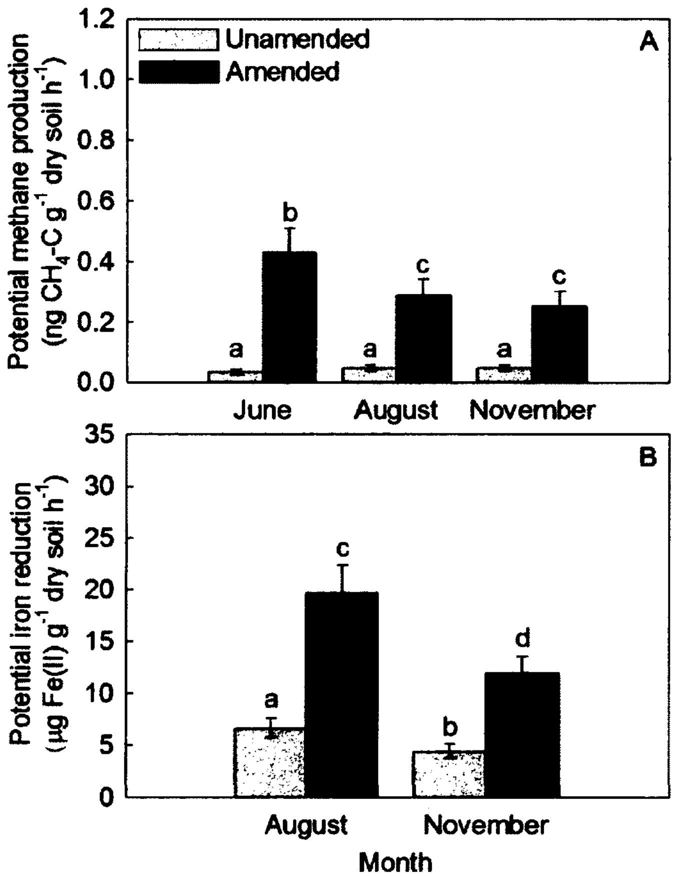


Figure 2.1. Potential methane production (A) and potential iron reduction (B) by month and substrate. Unamended (light bars) = soils incubated with water alone; amended (dark bars) = soils amended with 200 mM formate. All 16 treatments (including no-plant controls) included. Bars are geometric means with 95% CI. Within a panel, bars with different letters are significantly different (*P* < 0.05).

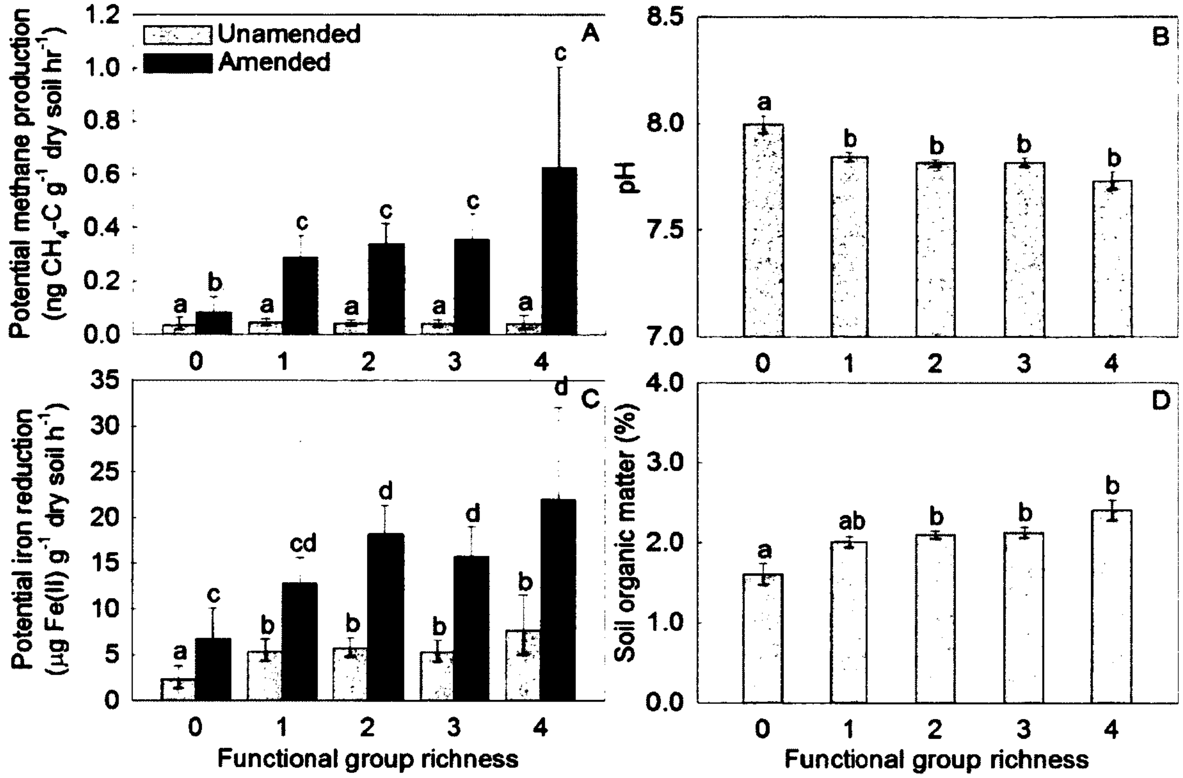


Figure 2.2. The effect of functional group richness on potential methane production (A), soil pH (B), potential iron reduction (C), and soil organic matter (D). Unamended (light bars) = soils incubated with water alone; amended (dark bars) = soils amended with 200 mM formate. All sampling months are included. For (A) and (C) bars are geometric means with 95% CI; for (B) and (D) bars are arithmetic means ± 1 SE.. Within a panel, bars with different letters are significantly different ($P < 0.05$). Note that the y-axis in (B) does not start at zero. Note also that the models for pH (B) and SOM (D) were not significantly better than the null models.

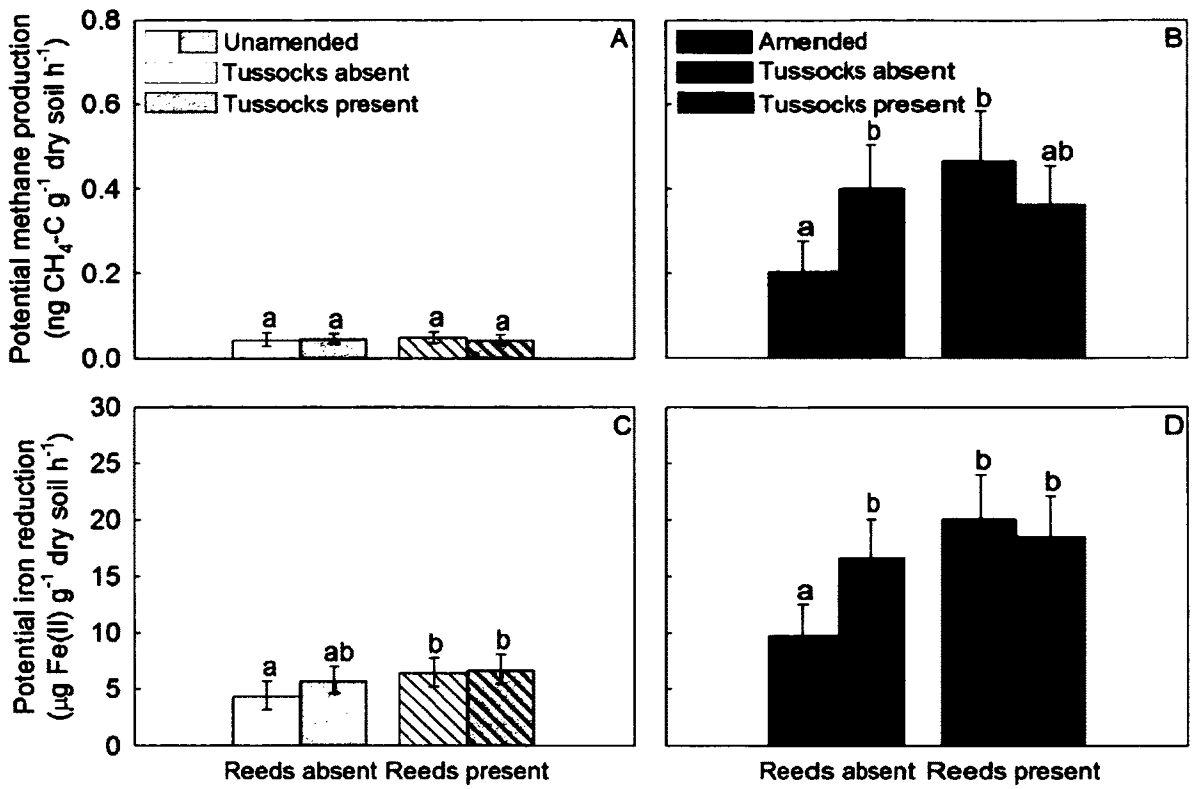


Figure 2.3. The effect of functional group composition on potential methane production (A and B) and potential iron reduction (C and D) for unamended (water only, lighter shades) and amended (200 mM formate, darker shades) soils. Within a panel lighter bars = absence of tussocks, darker bars = presence of tussocks, unhatched bars = absence of reeds, and hatched bars = presence of reeds. All sampling months are included but the no-plant controls were excluded from analysis. Bars are geometric means with 95% CI. Within a panel, bars with different letters are significantly different ($P < 0.05$).

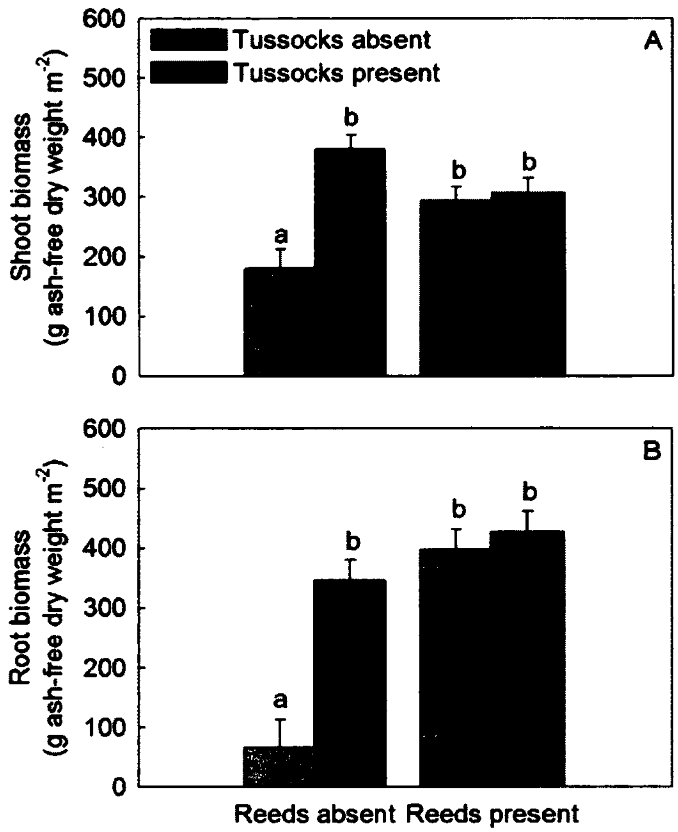


Figure 2.4. The effect of functional group composition on shoot biomass (A) and root biomass (B) at peak biomass (early September). In both panels light bars = absence of tussocks, dark bars = presence of tussocks, unhatched bars = absence of reeds, and hatched bars = presence of reeds. The no-plant controls were excluded from analysis. Bars are arithmetic means ± 1 SE. Within a panel, bars with different letters are significantly different ($P < 0.05$).

CONCLUSION TO PART I

In Part I of this dissertation I described research I undertook to better understand how structure influences function in freshwater wetland systems. In Chapter 1 I asked whether wetland structure (created or natural) or plant community structure (species richness) influenced methane cycling dynamics (potential methane production and potential methane oxidation). In Chapter 2 I asked whether plant community structure (composition and richness) in experimental mesocosm systems influenced carbon cycling dynamics (potential methane production and potential iron reduction).

In both studies, some aspect of wetland structure affected wetland function. Created wetlands had reduced rates of potential methane production and potential methane oxidation compared to natural wetlands. These differences were most likely explained by marked differences in edaphic factors that characterized each wetland, particularly soil moisture and soil organic matter. While the specific plant community structure component that I looked at (plant species richness) did not significantly affect methane dynamics in these wetlands, a different aspect of plant community structure (composition) examined as part of the larger study was shown to influence methane emissions more strongly than plant species richness (Schultz et al. 2011). Similarly, in my second study, plant functional group richness was less important than the type of vegetation present: the presence of perennial vegetation (reeds or tussocks) in wetland mesocosms led to increased rates of potential iron reduction compared to when only annual vegetation was present. Edaphic factors (soil organic matter and oxidized iron content) were also important in mediating potential methane production in the mesocosms. Together these studies showed that structure (created versus natural structures, differences in edaphic factors, differences in plant functional groups present) does affect function (methane and iron cycling) in freshwater wetland systems.

LITERATURE CITED IN PART I

Achtnich, C., F. Bak, and R. Conrad. 1995. Competition for electron donors among nitrate reducers, ferric iron reducers, sulfate reducers, and methanogens in anoxic paddy soil. *Biology and Fertility of Soils* 19: 65-72.

Andrews, S.E., R. Schultz, S.D. Frey, V. Bouchard, R. Varner, and M.J. Ducey. 2013. Plant community structure mediates potential methane production and potential iron reduction in wetland mesocosms. *Ecosphere* 4(4): art44.

Ballantine, K., and R. Schneider. 2009. Fifty-five years of soil development in restored freshwater depressional wetlands. *Ecological Applications* 19(6): 1467-1480.

Bouchard, V., S.D. Frey, J.M. Gilbert, and S.E. Reed. 2007. Effects of macrophyte functional group richness on emergent freshwater wetland functions. *Ecology* 88: 2903-2914.

Boutin, C., and P.A. Keddy. 1993. A functional classification of wetland plants. *Journal of Vegetation Science* 4: 591-600

Calhoun, A., and G.M. King. 1997. Regulation of root-associated methanotrophy by oxygen availability in the rhizosphere of two aquatic macrophytes. *Applied and Environmental Microbiology* 63: 3051-3058.

Callaway, J.C., G. Sullivan, and J.B. Zedler. 2003. Species-rich plantings increase biomass and nitrogen accumulation in a wetland restoration experiment. *Ecological Applications* 13: 1626-1639.

Castelletta, M., N.S. Sodhi, and R. Subaraj. 2000. Heavy extinctions of forest avifauna in Singapore: Lessons for biodiversity conservation in southeast Asia. *Conservation Biology* 14(6): 1870-1880.

Chanton, J.P., G.J. Whiting, J.D. Happell, and G. Gerard. 1993. Contrasting rates and diurnal patterns of methane emission from emergent aquatic macrophytes. *Aquatic Botany* 46: 111-128.

Chapin, F.S. III, E.S. Zavaleta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D.U. Hooper, S. Lovorel, O.E. Sala, S.E. Hobbie, M.C. Mack, and S. Diaz. 2000. Consequences of changing biodiversity. *Nature* 405: 234-242.

Christensen, T.R., N. Panikov, M. Mastepanov, A. Joabsson, A. Stewart, M. Öquist, M. Sommerkorn, S. Reynaud, and B. Svensson. 2003. Biotic controls on CO_2 and CH_4 exchange in wetlands – a closed environment study. *Biogeochemistry* 64: 337-354.

Coles, J.R.P., and J.B. Yavitt, J.B. Control of methane metabolism in a forested northern wetland, New York state, by aeration, substrates, and peat size fractions. *Geomicrobiology Journal* 19(3): 293-315.

Conrad, R. 1996. Soil microorganisms as controllers of atmospheric trace gases (H_2, CO, CH_4, OCS, N_2O, and NO). Microbiological Reviews 60: 609-640.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neil, J. Paruelo, R.G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.

Crozier, CR., I. Devai, and R.D. Delaune. 1995. Methane and reduced sulfur gas-production by fresh and dried wetland soils. *Soil Science Society of America Journal* 59: 227-284.

Dahl, T.E. 2000. *Status and Trends of Wetlands in the Conterminous United States 1986 to 1997*. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Dahl, T.E. 2006. *Status and Trends of Wetlands in the Conterminous United States 1998 to 2004*. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Dahl, T.E., and G.J. Allord. 1990. History of wetlands in the conterminous United States. Pages 19-26 *in* J.D. Fretwell, J.S. Williams, and P.J. Redman, editors. *National Water Summary of Wetland Resources*. U.S. Geological Survey Water-Supply Paper 2425, Washington, D.C.

D'Angelo, E.M., and K.R. Reddy. 1999. Regulators of heterotrophic microbial potentials in wetland soils. *Soil Biology & Biochemistry* 31: 815-830.

Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P.L. da Silva Dias, S.C. Wofsy, and X. Zhang. 2007. Couplings between changes in the climate system and biogeochemistry. Pages 500-587 *in* Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, editors. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Dunfield, P., R. Knowles, R. Dumont, and T.R. Moore. 1993. Methane production and consumption in temperate and subarctic peat soils: Response to temperature and pH. *Soil Biology & Biochemistry* 25: 321-326.

Engelhardt, K.A.M, and M.E. Ritchie. 2001. Effects of macrophyte species richness on wetland ecosystem functioning and services. *Nature* 411: 687-689

Fiedler, S., and M. Sommer. 2000. Methane emissions, groundwater levels, and redox potentials of common wetland soils in a temperate-humid climate. *Global Biogeochemical Cycles* 14(4): 1081-1093.

Findlay, C.S., and J. Bourdages. 2000. Response time of wetland biodiversity to road construction on adjacent lands. *Conservation Biology* 14: 86-94.

Findlay, C.S., and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario Wetlands. Conservation Biology 11: 1000-1009.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. Van Dorland. 2007. Changes in atmospheric constituents and in radiative forcing. Pages 129:234 *in* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, editors. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom, and New York, New York, USA.

Freeman, C., G.B. Nevison, H. Kang, S. Hughes, B. Reynolds, and J.A. Hudson. 2002. Contrasted effects of simulated drought on the production and oxidation of methane in a mid-Wales wetland. *Soil Biology & Biochemistry* 34: 61-67.

Frenzel, P. 2000. Plant-associated methane oxidation in rice fields and wetlands. Advances in Microbial Ecology 16: 85-114.

Frenzel, P., U. Bosse, and P.H. Janssen. 1999. Rice roots and methanogenesis in a paddy soil: Ferric iron as an alternative electron acceptor in the rooted soil. *Soil Biology & Biochemistry* 31: 421-430.

Geyer, J., I. Kiefer, S. Kreft, V. Ghavez, N. Salafsky, F. Jeltsch, and P.L. Ibisch. 2011. Classification of climate-change-induced stresses on biological diversity. *Conservation Biology*: 25: 708-715.

Goodwin, S., R. Conrad, and J.G. Zeikus. 1998. Influence of pH on microbial hydrogen metabolism in diverse sedimentary ecosystems. *Applied Environmental Microbiology* 54(2): 590-593.

Grünfeld, S., and H. Brix. 1999. Methanogenesis and methane emissions: effects of water table, substrate type and presence of *Phragmites australis*. *Aquatic Botany* 64: 63-75.

Hooper, D.U., F.S. Chapin III, J.J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J.H. Lawton, D.M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A.J. Symstad, J. Vandermeer, and D.A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs* 75: 3-35.

Hossler, K., and V. Bouchard. 2010. Soil development and establishment of carbon-based properties in created freshwater marshes. *Ecological Applications* 20(2): 539-553.

Hossler, K., V. Bouchard, M.S. Fennessy, S.D. Frey, E. Anemaet, and E. Herbert. 2011. No-net-loss not met for nutrient function in freshwater marshes: recommendations for wetland mitigation policies. *Ecosphere* 2: art82.

Houlahan, J.E., and C.S. Findlay. 2004. Effect of invasive plant species on temperate wetland plant diversity. *Conservation Biology* 18: 1132-1138.

Joabsson, A., and T.R. Christensen. 2001. Methane emissions from wetlands and their relationship with vascular plants: an Arctic example. *Global Change Biology* 7: 919-932.

Joabsson, A., T.R. Christensen, and B. Wallén. 1999. Vascular plant controls on methane emissions from northern peatforming wetlands. *Trends in Ecology and Evolution* 14: 385-388.

Kao-Kniffin, J., D.S. Freyre, and T.C. Balser. 2010. Methane dynamics across wetland plant species. *Aquatic Botany* 93: 107-113.

Keller, J.K., S.D. Bridgham, C.T. Chapin, and C.M. Iversen. 2005. Limited effects of six years of fertilization on carbon mineralization dynamics in a Minnesota fen. *Soil Biology & Biochemistry* 37: 1197-1204.

King, G.M. 1996. In situ analyses of methane oxidation associated with the roots and rhizomes of a bur reed, *Sparganium eurycarpum*, in a Maine wetland. *Applied and Environmental Microbiology* 62: 4548-4555.

Koelbener, A., L. Ström, P.J. Edwards, and H.O. Venterink. 2010. Plant species from mesotrophic wetlands cause relatively high methane emissions from peat soil. *Plant and Soil* 326: 147-158.

Krüger, M., P. Frenzel, and R. Conrad. 2001. Microbial processes influencing methane emissions from rice fields. *Global Change Biology* 7: 49-63.

Krüger, M., G. Eller, R. Conrad, and P. Frenzel. 2002. Seasonal variation in pathways of CH_4 production and in CH_4 oxidation in rice fields determined by stable carbon isotopes and specific inhibitors. *Global Change Biology* 8: 265-280.

Laanbroek, H.J. 2010. Methane emission from natural wetlands: Interplay between emergent macrophytes and soil microbial processes. A mini-review. *Annals of Botany* 105: 141-153.

Laurance, W.F., T.E. Lovejoy, H.L. Vasconcelos, E.M. Bruna, R.K. Didham, P.C. Stouffer, C. Gascon, R.O. Bierregaard, S.G. Laurance, and E. Sampaio. 2002. Ecosystem decay of Amazonian forest fragments: A 22-year investigation. *Conservation Biology* 16(3): 605-618.

Le Mer, J., and P. Roger. 2001. Production, oxidation, emission and consumption of methane by soils: A review. *European Journal of Soil Biology* 37: 25-50.

Littell, R.C, G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. *SAS for Mixed Models*, 2nd Ed. SAS Institute Inc., Cary, NC, USA.

Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, J.P. Grime, A. Hector, D.U. Hooper, M.A. Huston, D. Raffaelli, B. Schmid, D. Tilman, and D.A. Wardle. 2001. Biodiversity and ecosystem functioning: Current knowledge and future challenges. *Science* 294: 804-808.

Lovett, G.M., T.H. Tear, D.C. Evers, S.E.G. Findlay, B.J. Cosby, J.K. Dunscomb, C.T. Driscoll, and K.C. Weathers. 2009. Effects of air pollution on ecosystems and biological diversity in the eastern United States. *The Year in Ecology and Conservation Biology: Annals of the New York Academy of Sciences*. 1162: 99-135.

Lovley, D.R. 1985. Minimum threshold for hydrogen metabolism in methanogenic bacteria. Applied and Environmental Microbiology 49: 1530-1531.

Lovley, D.R., and E.J.P. Phillips. 1987. Rapid assay for microbially reducible ferric iron in aquatic sediments. *Applied and Environmental Microbiology* 53: 1536-1540.

MacDonald, J.A., D. Fowler, K.J. Hargreaves, U. Skiba, I.D. Leith, and M.B. Murray. 1998. Methane emission rates from a northern wetland; Response to temperature, water table, and transport. *Atmospheric Environment* 32: 3219-3227.

MacDonald, J.A., U. Skiba, L.J. Sheppard, K.J. Hargreaves, K.A. Smith, and D. Fowler. 1996. Soil environmental variables affecting the flux of methane from a range of forest, moorland and agricultural soils. *Biogeochemistry* 34: 113-132.

Mahaney, W.M., K.A. Smemo, and J.B. Yavitt. 2006. Impacts of *Lythrum salicaria* invasion on plant community and soil properties in two wetlands in central New York, USA. *Canadian Journal of Botany* 84: 477-484.

Megonigal, J.P., and W.H. Schlesinger. 2002. Methane-limited methanotrophy in tidal freshwater swamps. *Global Biogeochemical Cycles* 16: 1088-1097.

Miller, D.N., W.C. Ghiorse, and J.B. Yavitt. 1999. Seasonal patterns and controls on methane and carbon dioxide fluxes in forested swamp pools. *Geomicrobiology Journal* 16(4): 325-331.

Moreno-Mateos, D., M.E. Power, F.A. Comín and R. Yockteng. 2012. Structural and functional loss in restored wetland ecosystems. *PLoS Biology* 10(1): e1001247.

Naeem, S., L.J. Thompson, S.P. Lawler, J.H. Lawton, and R.M. Woodfin. 1994. Declining biodiversity can alter the performance of ecosystems. *Nature* 368: 734-736.

Neubauer, S.C., K. Givler, S. Valentine, and J.P. Megonigal. 2005. Seasonal patterns and plant-mediated controls of subsurface wetland biogeochemistry. *Ecology* 86: 3334-3344.

Rask, H., J. Schoenau, and D. Anderson. 2002. Factors influencing methane flux from a boreal forest wetland in Saskatchewan, Canada. *Soil Biology & Biochemistry* 34: 435-443.

Roden, E.E., and R.G. Wetzel. 1996. Organic carbon oxidation and suppression of methane production by microbial Fe(III) oxide reduction in vegetated and unvegetated freshwater wetland sediments. *Limnology and Oceanography* 41: 1733-1748.

Roden, E.E., and R.G. Wetzel. 2003. Competition between Fe(III)-reducing and methanogenic bacteria for acetate in iron-rich freshwater sediments. *Microbial Ecology* 45: 252-258.

Rosas, H.P., P. Moreno-Casaola, and I.A. Mendelssohn. 2006. Effects of experimental disturbances on a tropical freshwater marsh invaded by the African grass *Echinochloa pyramidalis*. *Wetlands* 26: 593-604.

SAS Institute Inc. 2008. SAS 9.2 Users Guide, Cary, NC: SAS Institute Inc.

Schimel, J.P. 1995. Plant transport and methane production as controls on methane flux from arctic wet meadow tundra. *Biogeochemistry* 28: 183-200.

Shindell, D.T., B.P. Walter, and G. Faluvegi. 2004. Impacts of climate change on methane emissions from wetlands. *Geophysical Research Letters* 31: 21202-21206.

Schooler, S.S., P.B. McEvoy, and E.M. Coombs. 2006. Negative per capita effects of purple loosestrife and reed canary grass on plant diversity of wetland communities. *Diversity and Distributions* 12: 351-363.

Schultz, R.E. 2010. Plant diversity and community composition effects on carbon cycling and nitrogen partitioning in freshwater wetlands. *Dissertation*. Ohio State University, Columbus, OH, USA.

Schultz, R., S. Andrews, L. O'Reilly, V. Bouchard, and S. Frey. 2011. Plant community composition more predictive than diversity of carbon cycling in freshwater wetlands. *Wetlands* 31: 965-977.

Schultz, R.E., V.L. Bouchard, and S.D. Frey. 2012. Overyielding and the role of complementary use of nitrogen in wetland plant communities. *Aquatic Botany* 97: 1-9.

Smialek, J., V. Bouchard, B. Lippmann, M. Quigley, T. Granata, J. Martin, and L. Brown. 2006. Effect of a woody (*Salix nigra*) and an herbaceous (*Juncus effusus*) macrophyte species on methane dynamics and denitrification. *Wetlands* 26: 509-517.

Sørensen, J. 1982. Reduction of ferric iron in anaerobic, marine sediment and interaction with reduction of nitrate and sulfate. *Applied and Environmental Microbiology* 43: 319-324.

Ström, L., M. Mastepanov, and T.R. Christensen. 2005. Species-specific effects of vascular plants on carbon turnover and methane emissions from wetlands. *Biogeochemistry* 75: 65-82.

Sutton-Grier, A., and J.P. Megonigal. 2011. Plant species traits regulate methane production in freshwater wetland soils. Soil Biology & Biochemistry 4: 413-420.
van der Nat, F.J.W.A., and J.J. Middelburg. 1998. Effects of two common macrophytes on methane dynamics in freshwater sediments. *Biogeochemistry* 43: 79-104.

Valentine, D.W., E.A. Holland, and D.S. Schimel. 1994. Ecosystem and physiological controls over methane production in northern wetlands. *Journal of Geophysical Research* 99(D1): 1563-1571.

Vann, C.D. and J.P. Megonigal. 2003. Elevated CO_2 and water depth regulation of methane emissions: Comparison of woody and non-woody plant species. *Biogeochemistry* 63: 117-134.

Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo. 1997. Human domination of Earth's ecosystems. *Science* 227: 494-499.

Welsch, M., and J.B. Yavitt. 2007. Microbial CO_2 production, CH_4 dynamics and nitrogen in a wetland soil (New York State, USA) associated with three plant species (*Typha, Lythrum, Phalaris*). *European Journal of Soil Science* 58: 1493-1505.

Whalen, S.C., and W.S. Reeburgh. 2000. Methane oxidation, production, and emission at contrasting sites in a boreal bog. *Geomicrobiology Journal* 17: 237-251.

Williams, C.J., and J.B. Yavitt. 2010. Temperate wetland methanogenesis: The importance of vegetation type and root ethanol production. *Soil Science Society of America Journal* 74: 317-325.

Wolf, K.L., C. Ahan, and G.B. Noe. 2011. Development of soil properties and nitrogen cycling in created wetlands. *Wetlands* 31: 699-712.

Yavitt, J.B. 1997. Methane and carbon dioxide dynamics in *Typha latifolia* (L.) wetlands in central New York State. *Wetlands* 17(3): 394-406.

Ye, R., Q. Jin, B. Bohannan, J.K. Keller, S.A. McAllister, and S.D. Bridgham. 2012. pH controls over anaerobic carbon mineralization, the efficiency of methane production, and methanogenic pathways in peatlands across an ombrotrophic-minerotrophic gradient. *Soil Biology & Biochemistry* 54: 36-47.

Zedler, J.B., and J.C. Callaway. 1999. Tracking wetland restoration: Do mitigation sites follow desired trajectories? *Restoration Ecology* 7: 69-73.

Zedler, J.B., J.C. Callaway, and G. Sullivan. 2001. Declining biodiversity: Why species matter and how their functions might be restored in California tidal marshes. *BioScience* 51: 1005-1017.

Zedler, J.B., and S. Kercher. 2005. Wetland resources: Status, trends, ecosystem services, and restorability. *Annual Review of Environment and Resources* 30: 39-74.

APPENDICES FOR PART I

APPENDIX 1: FIELD STUDY

Table A1.1. Mean (S.E.) potential methane oxidation (PMO), potential methane production (PMP), and environmental soil properties by wetland site.

Wetland		Potential methane rates ($ng\ CH_4\text{-}C\ g^{-1}$ dry soil h^{-1})		Environmental soil properties		
Type	Site	PMO	PMP	SOM (%)	Moisture (%)	pH
Created	Clover Groff	7.56 (1.40)	1.19 (0.31)	4.79 (0.21)	37 (6)	7.95 (0.08)
	Big Island	5.94 (0.95)	5.41 (3.69)	9.17 (0.18)	59 (2)	6.94 (0.06)
Natural	Ballfield	16.24 (3.58)	20.11 (8.64)	11.84 (0.92)	166 (25)	6.21 (0.12)
	Calamus	28.20 (4.82)	30.60 (17.25)	54.56 (4.63)	388 (36)	5.88 (0.06)

Notes: for potential methane oxidation and potential methane production, the rates for the two depths in a given plot were added together before calculating the average by site. SOM = soil organic matter.

APPENDIX 2: MESOCOSM STUDY

Table A2.1. Representative plant species planted in experimental mesocosms by functional group.

Functional group	Latin name	Common name
Facultative annuals	*Eupatorium perfoliatum* L.	Common boneset
	Lycopus americanus Muhl. ex W. Bart.	American water horehound
	Mimulus ringens L.	Allegheny monkeyflower
	Verbena hastata L.	Swamp verbena
Obligate annuals	*Bidens cernua* L.	Nodding beggartick
	Echinochloa muricata (Beauv.) Fern.	Rough barnyardgrass
	Panicum dichotomiflorum Michx.	Fall panicgrass
	Polygonum pensylvanicum L.	Pennsylvania smartweed
Reeds	*Eleocharis erythropoda* Steud.	Bald spikerush
	Eleocharis palustris L.	Common spikerush
	Juncus canadensis J. Gay ex Laharp	Canadian rush
	Juncus effusus L.	Common rush
Tussocks	*Acorus calamus* L.	Calamus or sweet flag
	Calamagrostis canadensis (Michx.) Beauv.	Bluejoint
	Carex crinita Lam.	Fringed sedge
	Scirpus cyperinus (L.) Kunth	Woolgrass

Table A2.2. Mean pH and soil organic matter (SOM) by plant functional group composition (FGC) treatment.

FGC	pH	SOM (%)
C	8.0 (0.04)	1.61 (0.13)
F	7.9 (0.04)	1.92 (0.12)
O	7.9 (0.04)	1.78 (0.12)
R	7.8 (0.04)	2.32 (0.13)
T	7.8 (0.04)	2.05 (0.13)
FO	7.9 (0.04)	1.99 (0.12)
FR	7.8 (0.04)	2.41 (0.12)
FT	7.8 (0.04)	2.06 (0.12)
OR	7.7 (0.04)	2.13 (0.12)
OT	7.9 (0.04)	2.06 (0.12)
RT	7.8 (0.04)	1.94 (0.12)
FOR	7.8 (0.04)	2.23 (0.13)
FOT	7.8 (0.04)	2.04 (0.13)
FRT	7.8 (0.04)	2.15 (0.12)
ORT	7.9 (0.04)	2.12 (0.13)
FORT	7.7 (0.04)	2.41 (0.12)

Notes: C = no-plant controls, F = facultative annuals, O = obligate annuals, R = reeds, T = tussocks. Means are arithmetic (SE).

Table A2.3. Mean potential methane production (PMP) and potential iron reduction (PIR) by plant functional group composition (FGC) treatment.

FGC	Unamended PMP ng CH_4-C/g dry soil/h	Amended PMP ng CH_4-C/g dry soil/h	Unamended PIR µg Fe(II)/g dry soil/h	Amended PIR µg Fe(II)/g dry soil/h
C	0.04 (0.02-0.06)	0.09 (0.05-0.14)	2.35 (1.40-3.67)	6.74 (4.54-9.81)
F	0.04 (0.02-0.07)	0.24 (0.15-0.37)	4.50 (2.94-6.69)	9.23 (6.32-13.28)
O	0.04 (0.02-0.07)	0.14 (0.08-0.22)	3.48 (2.16-5.37)	8.88 (6.07-12.80)
R	0.06 (0.04-0.10)	0.47 (0.29-0.75)	7.54 (5.11-10.93)	18.98 (13.30-26.91)
T	0.05 (0.03-0.08)	0.49 (0.31-0.77)	6.92 (4.67-10.06)	17.67 (12.15-25.50)
FO	0.04 (0.02-0.07)	0.16 (0.10-0.25)	3.49 (2.21-5.27)	11.05 (7.63-15.83)
FR	0.04 (0.02-0.07)	0.46 (0.30-0.73)	7.52 (5.10-10.91)	21.32 (14.97-30.17)
FT	0.04 (0.02-0.06)	0.43 (0.27-0.68)	5.95 (3.76-9.13)	16.04 (10.98-23.24)
OR	0.04 (0.02-0.08)	0.42 (0.26-0.67)	5.87 (3.91-8.59)	26.94 (19.00-38.04)
OT	0.06 (0.03-0.10)	0.35 (0.22-0.56)	5.69 (3.70-8.51)	17.12 (11.74-24.77)
RT	0.04 (0.02-0.07)	0.32 (0.20-0.50)	7.21 (4.88-10.48)	20.67 (14.51-29.27)
FOR	0.05 (0.02-0.08)	0.52 (0.33-0.81)	5.16 (3.34-7.74)	14.73 (10.26-20.98)
FOT	0.04 (0.02-0.06)	0.35 (0.22-0.55)	4.61 (3.02-6.84)	16.19 (11.31-23.02)
FRT	0.04 (0.02-0.07)	0.30 (0.19-0.48)	5.70 (3.79-8.36)	15.58 (10.87-22.17)
ORT	0.04 (0.02-0.08)	0.29 (0.18-0.45)	6.14 (4.11-8.97)	16.49 (11.52-23.44)
FORT	0.04 (0.02-0.07)	0.62 (0.40-0.97)	7.74 (5.25-11.20)	22.00 (15.46-31.13)

Notes: C = no-plant controls, F = facultative annuals, O = obligate annuals, R = reeds, T = tussocks. Means are geometric (95% CI).

Table A2.4. Linear mixed effect presence/absence model F values for main effects and significant interactions for root and shoot biomass.

Main effects and interactions	Root biomass	Shoot biomass
F	1.25	2.60
O	0.40	2.54
R	29.86***	0.58
T	17.02***	16.17***
*R*T*	11.01***	12.41***

Notes: Abbreviations as in Table 1. Only significant interactions were included. Numerator df = 1 and denominator df = 64. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

PART II: INTEGRATING ACTIVE-LEARNING INTO AN INTRODUCTORY SOIL SCIENCE COURSE

INTRODUCTION TO PART II

During my time as a graduate student conducting the wetland soil ecology research discussed in Part I of this dissertation I acted as a teaching assistant many times. Most valuable to me were my experiences as the teaching assistant for *Introduction to Soil Science* (Spring 2006, Fall 2006, and Fall 2008). These experiences led me to become increasingly interested not only in teaching science, but also in improving the way science is taught. Shortly after this I was presented with the opportunity to be the research assistant for Dr. Serita Frey's re-structure of the Introduction to Soil Science course (now Studio Soils).

I saw this as an excellent opportunity to increase my experiences in teaching and science education-based research and so I accepted this position. During the first year of this project our principle goal was to develop the necessary curriculum changes and to gather information on student learning. Through this work I became increasingly fascinated by curriculum design and innovative teaching/learning methods and decided to take on the greater challenge of coming up with my own research within the context of this re-structured course; this research is presented here in Part II my dissertation.

My long-term science education research goal is to understand how to better provide appropriate support and challenge to students to promote learning and growth. As part of reaching this goal, my overall objectives for this research were to 1) determine if there were any differences in student performance between the studio and traditional versions of the course, 2) understand Studio Soils students' ways of knowing (epistemological reflection), 3) understand students' perspectives on their experiences in Studio Soils, 4) look for relationships between students' perspectives and way of knowing, and 5) create a conceptual model of the Studio Soils experience. I describe the re-structure of the course and present the results of my research relating to my first objective in Chapter 3. Narratives of the ways of knowing exhibited by students who took Studio Soils (second objective) and students' perspectives on their experiences in Studio Soils (third objective) are presented in Appendix 4. I explore connections between students' perspectives and ways of knowing (fourth objective), and the resulting conceptual model (fifth objective) in Chapter 4. Though not part of my original objectives, I also wrote a short opinion piece recommending the studio learning environment, presented as Chapter 5.

CHAPTER 3

STUDIO STRUCTURE IMPROVES STUDENT PERFORMANCE IN AN UNDERGRADUATE INTRODUCTORY SOIL SCIENCE COURSE

Abstract

There has recently been an increase in the number of classrooms implementing active learning strategies in lectures. The studio structure takes this a step further by integrating active learning strategies into an environment where lectures and labs have been combined. Most research on such course modifications has taken place in physics, chemistry, or biology; there has been very little research conducted in natural resource fields. In addition, the research that has been conducted often fails to consider differences due to gender or between lower- and higher-performing students. Here I describe the modification of an introductory soil science course from a traditional lecture-lab format to a studio structure. The primary objective of this study was to determine if this modification influenced student performance in the course. In addition I was interested in whether the modification differentially influenced lower- versus higher-performing students or male versus female student performance. I found that students taking the studio course obtained higher final grades than those taking the traditional course and that the fail rate was significantly lower in the studio course. Additionally, lower performing students made greater gains in the studio relative to the traditional course. Female students outperformed male students in both the studio and traditional courses, but there was some evidence for the gap closing in the studio course (on exam

performance only). These findings show that the studio structure can improve student performance in an introductory soil science course and that this structure can be especially helpful for lower-performing students.

Introduction

The effectiveness of traditional lecture-based courses has increasingly come under question primarily because lectures tend to focus on passive transfer of information; it has been argued that education should become less about transferring information and more about gaining a conceptual understanding of course material (Mazur 2009). Others (Handelsman et al. 2004) discuss the need for implementing change in lectures and encourage the incorporation of active learning strategies that have been shown to engage students in their own learning and the scientific process. Such strategies require students to apply what they are learning in the classroom by doing activities, thinking about what they are doing, and sharing their ideas with their peers and instructors (Bonwell and Eison 1991, Meyers and Jones 1993, Armbruster et al. 2009). A growing number of studies conducted over the last two decades have examined the implementation of active learning strategies into lecture courses, primarily in the areas of physics (Meltzer and Manivannan 2002, Dori and Belcher 2005, Deslauriers and Wieman 2011, Efthimiou et al. 2011), chemistry or biochemistry (Lewis 2011, González-Sancho et al. 2013, Lian and He 2013), and biology (Ebert-May et al. 1997, Udovic et al. 2002, Freeman et al. 2007, Armbruster et al. 2009, Preszler 2009, Haak et al. 2011, Jensen and Lawson 2011). Some studies have gone a step beyond incorporating active learning strategies into a lecture and have integrated active learning into an environment that combines the lecture and lab into one (Oliver-Hoyo et al. 2004, Gottfried et al. 2007, Montelone et al. 2008, Gatch 2010, Nogaj 2013). This approach, commonly referred to as a 'studio' approach, promotes active engagement of students in their own learning by integrating lab experiments into the class, incorporating computer-based data analysis, and allowing instructors to interact more with students (Beichner et al, 2007).

Most research on the implementation of some form of active learning into lectures in physics, chemistry, or biology has shown improved performance relative to lecture-based courses on a variety of assessments, including final grades and/or pass rate (Beichner et al. 2007, Preszler 2009, Freeman et al. 2011, Haak et al. 2011, Lewis 2011, Ueckert et al. 2011), exams (Wright et al. 1998, Freeman et al. 2007, Armbruster et al. 2009, Walker et al. 2008, Yadav et al. 2011, González-Sancho et al. 2013, Lian and He 2013), and standard concept inventories (Hake 1998, Crouch and Mazur 2001, Lorenzo et al. 2006, Beichner et al. 2007, Brewe et al. 2010, Deslauriers and Wieman 2011, Efthimiou et al. 2011). Additionally, most studies that have showed no difference in student performance between lecture-based and active-learning structures have either documented improved performance on some assessments but not others (Ebert-May et al. 1997, Lewis 2011), or have documented other benefits such as improved attitudes (Bull and Clausen 2000, Gottfried et al. 2007). There are no published studies, to my knowledge, where performance was observed to be consistently lower in active-learning environments compared to lecture-based courses, and only one study where no differences of any kind were found (Andrews et al. 2011). While there is ample support for the benefits of active-learning in physics, biology, and chemistry, there are comparatively fewer studies for natural resource courses such as water resources (Bull and Clausen 2000), forestry (Thompson et al. 2003), and soil science (Amador and Görres 2004).

Most studies on the implementation of active learning strategies (across all disciplines) have focused on overall student achievement and have not assessed how the implementation of active learning strategies influences the achievement of lower-performing students. In physics, female students have consistently been shown to underperform compared to their male peers (see Madsen et al. 2013 for a review). There has been far less research on gender gaps in other fields such as biology, chemistry, or natural resources, and what little research there is shows inconsistent results. Research in these fields has sometimes shown a gender gap favoring male students (Henrie et al. 1997 (geography), Rauschenberger and Sweeder 2010 (biochemistry), Creech and Sweeder 2012 (life sciences)) and other times favoring female students (Pearsall et al. 1997 (biology), Higham and Steer 2004 (gynecology and obstetrics)); others have found no evidence of a gender gap (Wright et al. 1998 (chemistry), Lauer et al. 2013 (biology and biochemistry)). While most active-learning research has not looked at the influence of course modifications on achievement gaps (gender-based or other), some studies have found that implementing active-learning strategies can reduce the gender gap (Lorenzo et al. 2006), reduce the gap between economically disadvantaged and privileged students (Haak et al. 2011), or reduce the gap between lower- and higher-performing students (Dauer et al. 2013). However, other studies have shown either no change or an increase in the gender gap with the implementation of active learning strategies (Pollock et al. 2007, Kost et al. 2009, Brewe et al. 2010, Kost-Smith et al. 2010).

Here I describe the re-structuring of an undergraduate introductory soil science course in the Department of Natural Resources at the University of New Hampshire, Durham. Prior to 2010 the course was taught in a traditional lecture-based structure with a separate lab. Beginning in 2010 this traditionally taught course was modified into a studio course where the lecture and lab components were combined and integrated with cooperative active-learning exercises. The purpose of this study was to examine the impact of this modification on student learning, which was based on students' performance on quizzes, reports, and exams, and on students' final grade in the course.

In addition to examining the impact on overall student performance, I was also interested more specifically on the impact of the modification on lower-performing students (based on their GPA prior to taking the course). Finally, because there is a paucity of research on gender differences in achievement in natural resource fields, I was interested in determining if a gender gap was present in the course.

More specifically this study addresses the following research questions: 1) What is the influence of a studio structure on student performance in an undergraduate soil science course?; 2) Does the modification to a studio structure differentially influence the performance of lower- compared to higher-performing students?; 3) Is there evidence of a gender gap in performance in this course?; and 4) If there is evidence of a gender gap, does the studio structure influence the size of the gap?

Based on the research discussed above, I hypothesized that 1) students in the studio course would outperform students who took the traditional course; 2) the gap between traditional and studio student performance would be greater for lower-performing students than higher-performing students; 3) no gender gap would be present in the course; and 4) *if* a gender gap *was* present, the gap would diminish in the studio structure relative to the traditional structure.

Materials and Methods

Setting and participants

Studio Soils (formerly Introduction to Soil Science) is a fall semester course offered yearly at the University of New Hampshire; it is required for all students majoring in Environmental Conservation and Sustainability, Environmental Science, and Forestry, though the course is open to all students. The course is designed to cover the fundamental concepts of soil science; by the end of the course students should be able to describe the important role of soils in the environment, describe fundamental physical, chemical, and biological properties of soils and their effects on plant growth and the environment, and identify, compare, and contrast soils in the landscape. Prior to 2009, the course was taught in a traditional structure: three 50 minute lectures with four separate 2 hour lab sections. All students (typically 60-80) met together for the lecture with a maximum of 20 students per lab section (working in groups of four). In 2010 the course was re-structured into a studio structure where the lecture and lab portions were integrated into two 2-hour long sessions per week; the course was broken into two sections capped at 36 students (working in groups of three). While the structure of the course changed, the overall course objectives and course content remained the same before and after modification.

In the traditional course, lectures were occasionally punctuated with brief learner-centered activities (such as think-pair-share), but all hands-on lab and field work was conducted in the lab session. To align with principles of active learning (students apply learning by doing, thinking, and sharing; Bonwell and Eison 1991, Meyers and Jones 1993) and following the examples of others (e.g. Beichner et al, 2007), the studio course was designed to incorporate hands-on activities, data analysis, short writing assignments (group and individual), and small group discussions. A typical class is comprised of one or two mini-lectures (approximately 15 minutes in length) separated by periods in which students are engaged in one or more of these activities. For example, during one class period the instructor presented a mini-lecture on soil formation, after which students worked together in their groups of three on an activity where they interpreted maps of bedrock, surficial geology, and soils (within a particular region) and then discussed and answered a series of questions. This activity was followed up by a class discussion, which led into an introduction of soil texture. Students then worked on a soil texture activity that combined hands-on texture-by-feel practice, using a texture triangle, and discussion questions linking soil texture to other soil properties (i.e. permeability, compaction). The class session ended with students working individually on a short writing assignment (see Appendix 3 for the soil formation and soil texture activities and for the short writing prompt).

In addition to implementing active learning strategies into a studio structure, the course was reorganized into four units based on soils interactions with earth system spheres (lithosphere, biosphere, hydrosphere, and atmosphere) and some topics that were taught as a single unit in the traditional course were spread out across all four units in the studio course. For example, instead of learning about soil taxonomy and soil formation all at once, as in the traditional course, students learned about soil taxonomy and soil formation in the beginning of the studio course and revisited these concepts every unit in the context of learning about two or three new soil orders that were particularly relevant for that unit (e.g. in the Biosphere unit students learned about soil orders for which vegetation plays a major role in their formation (Mollisols, Alfisols, and Spodosols)).

This study took place during the last year the course was taught in the traditional structure (2009) and the first two years it was taught in the studio structure (2010 and 2011). Minimal changes were made to the studio course between 2010 and 2011; these changes were focused on improving clarity of expectations (minor revisions to some activities) and making the class sessions run more smoothly (moving quizzes from the beginning of class to online before class, adjusting time allotted for some activities). In the traditional course, the primary professor taught the lectures, while two teaching assistants taught the four lab sections. The studio course was co-taught by the same primary professor and an additional instructor (the author). One teaching assistant was also present for each of the two sections. The teaching assistants were the same for the traditional course and the first studio year; two different teaching assistants were involved in the second studio year. All instructors were female except one teaching assistant in 2011.

The course is intended for second-year students; however enrollment was dominated by third and fourth-year students each year of the study (Table 3.1). Total enrollment was between 70 and 72 students each year. The ratio of female to male students was close to even each year, ranging from 0.7 to 1.1 (Table 3.1). All three years were dominated by students in the Environmental Conservation and Sustainability major (56-65%; Table 3.1). There were no statistical differences in demographics between course structures (Table 3.1).

Data collection

The data that were used in this study were student grades (average quiz, report, and exam grades and their final grade), gender, year in school, and grade point average (GPA). Student's gender, year in school, and GPA were self-reported as part of a demographic questionnaire (Appendix 5); if a student granted permission to access their records, their GPA was verified via their academic transcript. Institutional Review Board (IRB) approval was obtained for this research (IRB #5243 and #5313; Appendix 7) and informed consent for use of grades, use of the questionnaire, and permission to access students' GPA from their transcript was sought from all students through the use of a consent form for participation in a research study involving human subjects (Appendix 6).

A student's major was also considered as a variable but because most students majored in Environmental Conservation and Sustainability each year of the study there was not enough variability to assess differences in performance for this parameter. Other variables were also considered but were not used for various reasons (see Appendix 3 for a discussion of these other potential variables).

Quizzes (9-15 per semester) were a combination of short answer, multiple choice, and true false (5-10 questions total) and were given in the first 10 minutes of class in the traditional course and the first year of the studio course; in the second studio year quizzes were moved to an online platform (Blackboard 9.1) and were completed prior to class. Thus, in all years the quizzes occurred prior to instruction. Each year students worked on four separate research projects culminating in a final report; in both the traditional and studio structures students worked together in their groups to complete lab and field work but wrote their own individual research reports. While the topics for the projects varied slightly from year to year, the format for three of the four research reports remained the same. In the studio course one of the four written research reports was replaced with an oral PowerPoint presentation. The format for the exams and the time allotted to complete each exam (50 minutes) remained the same across all three years; each exam was made up of short answer, multiple-choice, true-false, and short essays. There were three exams in the traditional course and four exams in the studio course; there was no cumulative final exam for either the traditional or studio structures. While the final grade was calculated slightly differently year to year in the actual course, I recalculated final grades for the purposes of this research project to ensure that the calculations were equivalent across all three years. Thus, for the purposes of this research, quizzes, reports, and exams made up 20%, 40%, and 40% of the final grade respectively. Students' final grades were used to calculate the fail rate (percent of students who failed the course) for the traditional and studio courses. In general a final grade less than 60% is considered a failing grade; however, students in the Environmental Conservation and Sustainability major (56-65% of students) must pass with a final grade greater than or equal to 70%. Therefore I calculated the fail rate for students receiving less than 60%, as well as for students receiving less than 70%.

Statistical analyses

In order to verify that there were no demographic differences between the students in the two course structures, I used an independent samples *t*-test for GPA, a 2x2 contingency table analysis for students' gender (Fisher's exact probability test), and 2x3 contingency table analyses for year in school and major (Freeman-Halton extension of Fisher's test). I also used a 2x2 contingency table analysis to test whether there was a difference in fail rate between the traditional and studio structures (Fisher's exact probability test).

In order to test for differences in students' grades due to course structure (traditional and studio), students' gender (male and female), and their year in school (2^{nd}, 3^{rd}, and 4^{th}), I performed separate linear mixed effects models (Proc Mixed, SAS 9.3) for each assessment type (quiz, report, exam, final grade). Structure, gender, and year in school were used as fixed effects and section (four sections in 2009 and two each for 2010 and 2011) was specified as a random effect (nested within year). I was also interested in students' GPA as a covariable; however, because GPA was significantly related to students' gender, and marginally significantly related to students' year in school (Table 3.2, Figure 3.1), GPA could not be a covariable in models that included gender and year in school. In addition, I was missing GPA for 20% of students (those who did not consent to transcript access). Therefore, I first performed the analysis without GPA (data from all students) to test for differences due to course structure, students' gender, and students' year in school, and then repeated the analyses using only course structure as the fixed effect and GPA as a covariable. In all cases I started with full models and reduced the model by removing insignificant interactions, starting with the higher order interactions and removing those with larger *P* values first.

Results

Effects of course structure and student gender on performance

Students who took the studio structure obtained significantly higher final (84%) and report grades (87%) than students who took the traditional structure (80% and 79%, respectively; Figure 3.2 A and B). However, there was no difference in student performance on quizzes (79% for both structures, Figure 3.2 C). Female students earned significantly higher final grades than male students (84 and 80%, respectively), and also performed significantly better than male students on quizzes (80 and 76%, respectively; Figure 3.2 D and F). For exams there was a significant interaction between course structure and students' gender (Table 3.2): in the traditional structure, female students performed better on exams than male students (84 and 77%, respectively), but there was no statistical difference due to student gender in the studio structure (Figure 3.3). Male students who took the studio structure performed better on exams than male students who took the traditional structure (84 and 77%, respectively), but there was no difference in exam performance between course structures for female students (Figure 3.3). A student's year in school was not a significant effect for any assessment type except quizzes (Table 3.2); student quiz grades declined with increasing year in school (from 83% in 2nd year students to 75% in 3rd year students; data not shown).

Fail-rate

There was no statistical difference between the two course structures for the percentage of students who received less than a 60% as their final grade in the course (X^2 (1) = 0.38, P = 0.26). However, the percentage of students who received less than 70% decreased significantly from 14% in the traditional structure to 4% in the studio structure (X^2 (1) = 6.35, P = 0.02, Figure 3.4).

GPA as a predictor of performance

Student grade point average (GPA) was a strong predictor of their final grade in the course and of their performance on reports, exams, and quizzes (Figure 3.5). However, for every assessment type except quizzes there was an interaction between GPA and course structure (Table 3.3); at high GPAs there was no difference in student performance between the two course structures, but at lower GPAs, students who took the studio structure outperformed students who took the traditional structure (Figure 3.5). In addition, the strength of the relationship between student grades and GPA was stronger in the traditional structure ($r^2 = 0.56$ to 0.66) than in the studio structure ($r^2 = 0.16$ to 0.30; Figure 3.5).

Discussion

I studied the modification of an introductory soil science course from a traditional lecture-based course with a separate lab to a studio course where the lecture and lab were combined and integrated with active-learning strategies. I hypothesized the following: 1) students in the studio course would outperform students who took the traditional course; 2) the gap between traditional and studio student performance would be greater for lower-performing students than higher-performing students; 3) there would be no gender gap present in the course; and 4) if a gender gap existed, the size of the gap would diminish in the studio course relative to the traditional course.

I found that students in the studio course had significantly higher final grades than students in the traditional course. When failure was considered to be a final grade < 70%, the case for Environmental Conservation and Sustainability majors (~60% of students in the course), significantly fewer students failed the studio course compared to the traditional. These findings support my first hypothesis. Others have frequently found improved grades or reductions in fail rate in courses where active learning has been implemented (Beichner et al. 2007, Preszler 2009, Freeman et al. 2011, Haak et al. 2011, Lewis 2011, Ueckert et al. 2011) so this finding was not unexpected. I did find that there was no difference on students' quiz performance between the two structures, but because quizzes were completed prior to instruction, it is not very surprising that the form of instruction had no impact. In addition to higher final grades, students in the studio course performed better on their research reports than students in the traditional course. One of the reports in the studio course was an oral presentation that was not part of the traditional course, but there was no difference between average report grade with and without this oral presentation (data not shown) so the improved performance on reports in the studio year cannot be explained by inflation due to the oral report. Compared to the traditional course, when students had minimal time to work on their reports during lab, students in the studio course analyzed data together during class and worked together drafting small portions of their reports (e.g., objectives, hypotheses, figure captions). It is likely that these activities led to improved performance on the research reports, though I cannot rule out the possibility that it was simply extra-time-on-task that resulted in improved report grades.

While course structure was a significant influence on student performance, I also found that GPA was a strong predictor of performance on quizzes, reports, and exams, and a strong predictor of their final grade in the course, for both the traditional and studio structures. This relationship between GPA and performance was expected as it has consistently been found across a wide variety of disciplines including the biological sciences (Freeman et al. 2007, Wright et al. 2009, Rauschenberger and Sweeder 2010, Freeman et al. 2011, Creech and Sweeder 2012, Dauer et al. 2013), chemistry (Easter 2010, Dianovsky and Wink 2012), physics (Bonaham et al. 2003, Hsieh 2012), engineering

(Huang and Fang 2013), and business/management (Brookshire and Palocsay 2005, Michel et al. 2009). While some of the above research was done in the context of studying the influence of active-learning strategies on student performance (Michel et al. 2009, Freeman et al. 2007, Freeman et al. 2011), these studies did not examine the impact of active learning on the relationship between GPA and performance. In fact, little research has been done on whether active-learning can impact this relationship. Because teaching is a purposeful activity, faculty often assume that their teaching style can influence student performance; this assumption is heightened in the context of implementing active-learning because the purpose of such implementation is typically to improve student learning. Thus, while it makes sense that a student's prior academic performance (GPA) should be related to their future performance, student performance should also be influenced by the effectiveness of instruction (i.e. the effectiveness of the instructor, teaching method, and/or environment). I would argue that as the ability of GPA to predict performance increases, the influence of instruction on performance decreases. While I found that GPA was a predictor of performance for both the traditional and studio structures, the strength of this relationship was stronger in the traditional structure relative to the studio, suggesting that traditional instruction had less influence on student performance than studio. In addition, I found an interaction between course structure and GPA for student performance on reports and exams and for their final grade in the course: there was no difference in student performance between the two structures for students with GPAs higher than ~3.4 (25% of students), but students in the studio course who had GPAs lower than 3.4 (75% of students) performed better than students in the traditional course with equivalent GPAs. This finding supports my second hypothesis that lower-performing students would improve to a greater degree than higher-performing students in the studio course. Dauer et al. (2013) also found that achievement gains (before and after cooperative group work) in low-performing students (based on their incoming GPAs) were greater than those in high-performing students. While there has been little research looking at the influence of active-learning on low- versus high-performing students based on their incoming GPA, some studies have found that implementing active-learning strategies can reduce the gap between female (lower-performing) and male (higher-performing) physics students (Lorenzo et al. 2006) or reduce the gap between economically disadvantaged (lower-performing) and privileged (higher-performing) biology students (Haak et al. 2011). However, other studies have shown either no change or an increase in an achievement gap with the implementation of active learning strategies (Beichner et al. 2007, Pollock et al. 2007, Kost et al. 2009, Brewe et al. 2010, Kost-Smith et al. 2010). Thus, while my data supports the findings of others that active-learning *can* be especially beneficial for lower-performing students, the fact that many have found no specific benefit, or an opposite effect, suggests that more research needs to be done to determine which specific teaching strategies and environments are more (or less) beneficial for lower-performing students. It should also be noted that in addition to implementing active learning strategies in a studio environment, Studio Soils was also restructured to align content with the earth system spheres and some material (primarily soil taxonomy) was spaced out over the whole semester. Spacing (revisiting the same concept after a delay) has consistently been shown to improve recall and learning (as discussed by Paschler et al. 2007, Kornell and Bjork 2008, and Mayer 2011). Thus it is possible that the increased performance could be due to these changes in the way the material was presented in addition to, or instead of, the use of active learning strategies.

Female students consistently outperformed male students in both the studio and traditional course, which does not support my third hypothesis that there would be no gender gap. One possible explanation for this is that the primary professor, co-instructor and all but one of the teaching assistants were female, and that the presence of female role-models improved female student performance in this course. While there is some evidence for a positive influence of competent female role-models on female student performance on math tests (Marx and Roman 2002), I also found that female students had higher GPAs on average than male students, suggesting that the gender gap between male and female students was not unique to this class but rather was a product of prior performance in their program of study. Interestingly, while male students have consistently been shown to outperform female students in physics (Lorenzo et al. 2006, Pollock et a. 2007, Kost et al. 2009, Willoughby and Metz 2009, Brewe et al. 2010, Kost-Smith et al. 2010, Miyake et al. 2010), there is much less evidence for a gender gap in life sciences or natural resource fields. The research that exists has sometimes shown that no gender gap exists (Wright et al. 1998, Lauer et al. 2013), that the gender gap favors male students (Henrie et al. 1997, Rauschenberger and Sweeder 2010, Creech and Sweeder 2012), or that the gender gap favors female students (Pearsall et al. 1997, Higham and Steer 2004). While research on gender differences in the natural resources needs to continue, my findings support the findings of others that have shown a gap favoring females. Additionally, while I found the opposite gender gap as that typically seen in physics, I found that the gap that was present in the traditional course persisted into the studio course. While I did see some evidence for the gap closing for exam performance, partially supporting my fourth hypothesis, female students still outperformed male students on quizzes and reports and achieved higher final course grades on average. In a review of the gender gap in physics, Madsen (2013) found that the use of interactive techniques was not always successful at reducing the gender gap and that the biggest determinant was background experience in physics. While most of our students had little to no direct soils related experience, the fact that female students had higher GPAs than male students does suggest that previous gender differences in academic success were at least partially responsible for gender differences in our course.

Conclusions

I found that students who took the studio course obtained higher final grades than students who took the traditional course and that the fail rate was significantly lower in the studio course. In addition, the gap in student performance between studio and traditional formats was greater for lower-performing students, and the strength of GPA as a predictor of performance declined in the studio course compared to the traditional course. I also found that female students outperformed male students in both course structures, which is best explained by differences in their GPA before entering the class (female students had a higher GPA on average). While female students outperformed male students on quizzes and reports and achieved higher final course grades, there was some evidence for the gap closing for exam performance. Taken together these findings show that the studio structure can improve student performance in introductory soil science and that this structure can be especially helpful for lower-performing students.

Table 3.1. Demographics of students by year in the two course structures compared in this study.

					By Year in School (%)			By Major (%)		
Course structure	Year	Enrollment	Mean GPA	Gender Ratio (F/M)	2nd	3rd	4th	ECS	Other NR	Non-NR
Traditional	2009	72	3.14	1.1	25	50	25	65	22	13
Studio	2010	71	3.00	0.7	20	45	35	63	17	20
	2011	70	3.03	0.9	14	46	39	56	31	13

Notes: There were no statistical differences between course structures: GPA t (168) = 1.57, P = 0.12; Gender X^2 (1) = 1.04, P = 0.31; Year in School X^2 (2) = 3.79, P = 0.15; Major X^2 (2) = 0.79, P = 0.70. ECS = Environmental Conservation Sustainability, Other NR = other Natural Resource majors, Non-NR = non-Natural Resource majors.

Table 3.2 Linear mixed effect model F values (num df, den df) for main effects (course structure, students' gender, and students' year in school) and significant interactions from treatment-only models (no covariable) using assessment types (Quiz, Report, Exam, Final) and grade point average (GPA) as dependent variables.

Effect	Quiz	Report	Exam	Final	GPA
Course Structure	0.05 (1, 6) ns	8.05 (1, 7)*	16.26 (1, 10)**	6.88 (1, 7)*	0.81 (1, 6) ns
Gender	4.62 (1, 204)*	2.93 (1, 205)†	14.48 (1, 200)***	7.73 (1, 206)**	11.71 (1, 165)***
Year in school	3.09 (2, 203)*	2.81 (2, 199)†	0.21 (2, 200) ns	1.67 (2, 186) ns	2.88 (2, 130)†
Course Structure*Gender			5.05 (1, 200)*		

Note: ns = not significant, † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 3.3 Linear mixed effect model F values (num df, den df) for main effect (course structure) and covariable (GPA) from analysis of covariance models using assessment types (Quiz, Report, Exam, Final) as dependent variables.

Effect	Quiz	Report	Exam	Final
Course Structure	0.12 (1, 10) ns	11.13 (1, 10)**	24.14 (1, 10)***	10.10 (1, 10)**
GPA	34.67 (1, 161)***			
GPA*Course Structure		36.58 (2, 160)***	80.96 (2, 160)***	66.73 (2, 160)***

Note: ns = not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

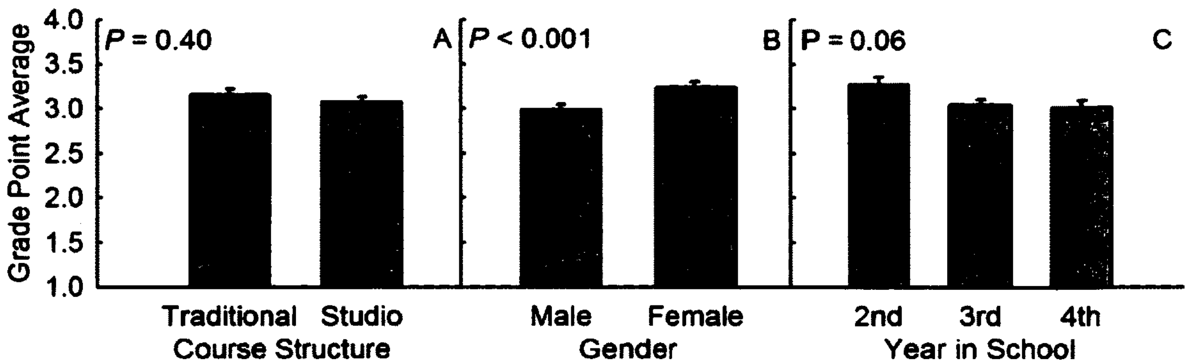


Figure 3.1. Main effects of treatment (course structure (A), student gender (B), and student's year in school (C)) on grade point average (N = 170).

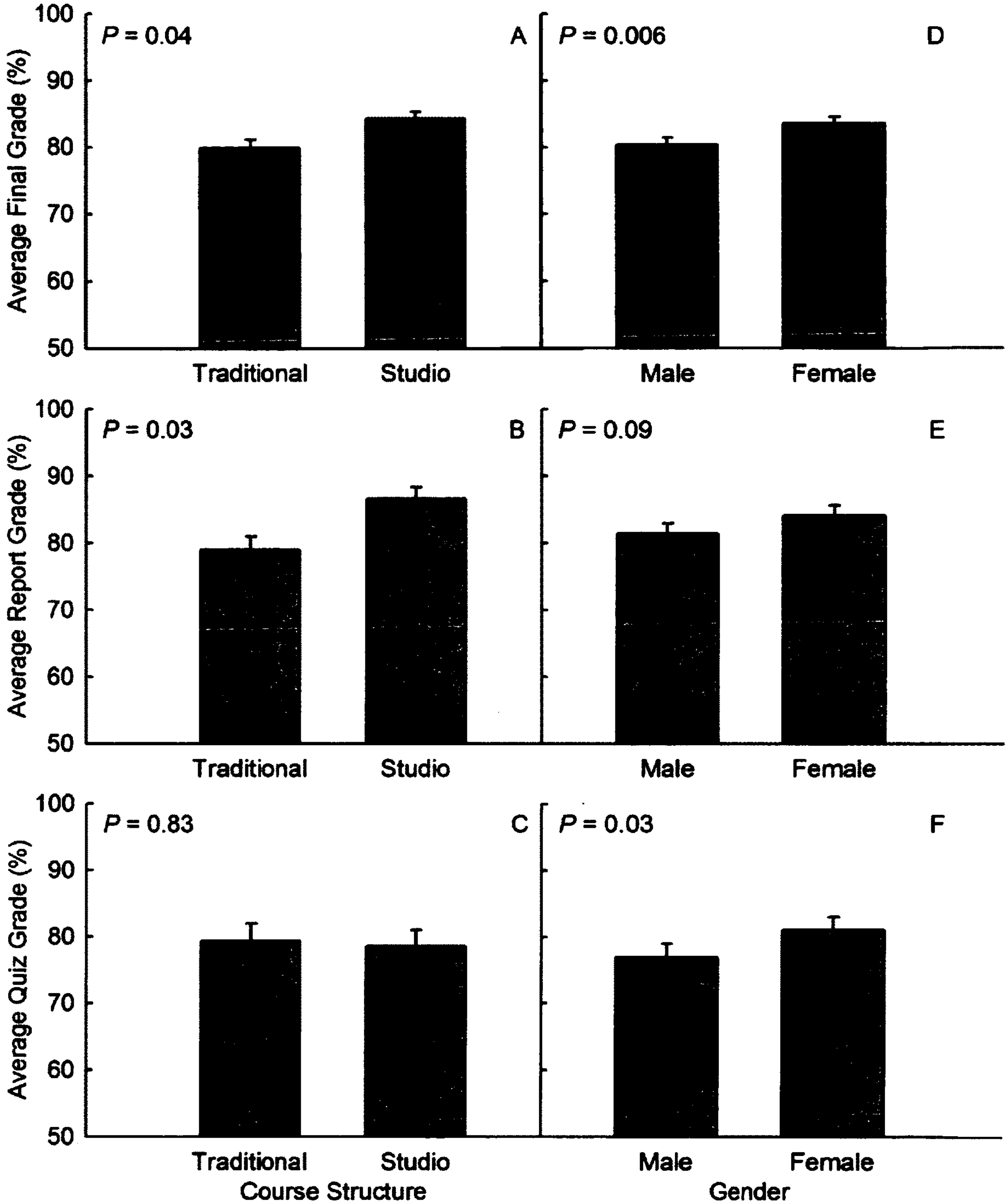


Figure 3.2. The effects of course structure (left) and students' gender (right) on average final grade (A, D), report grade (B, E), and quiz grade(C, F). N = 213.

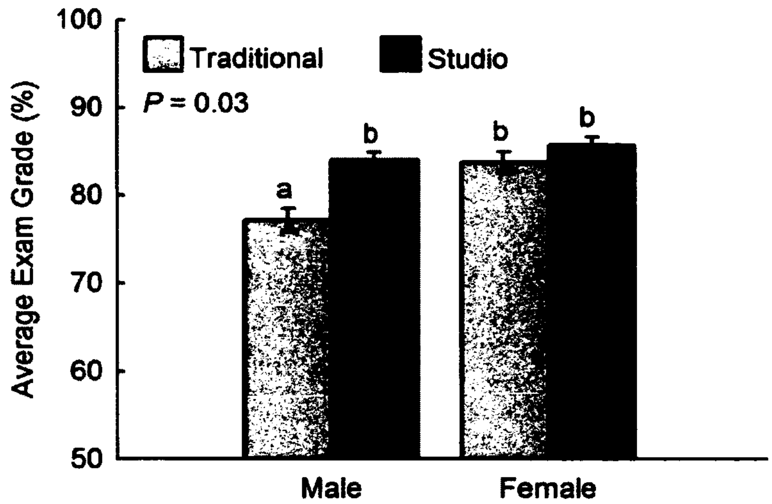


Figure 3.3. The interactive effects of course structure and students' gender on average exam grade. N = 213.

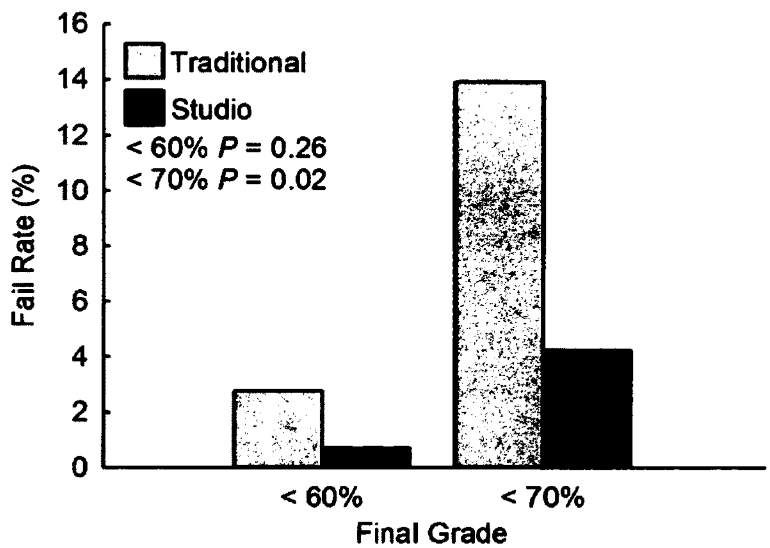


Figure 3.4. Fail rate by course structure. Less than 60% is a failing grade for any student; less than 70% is failing grade for any student for whom the class is a requirement for their major. N = 213.

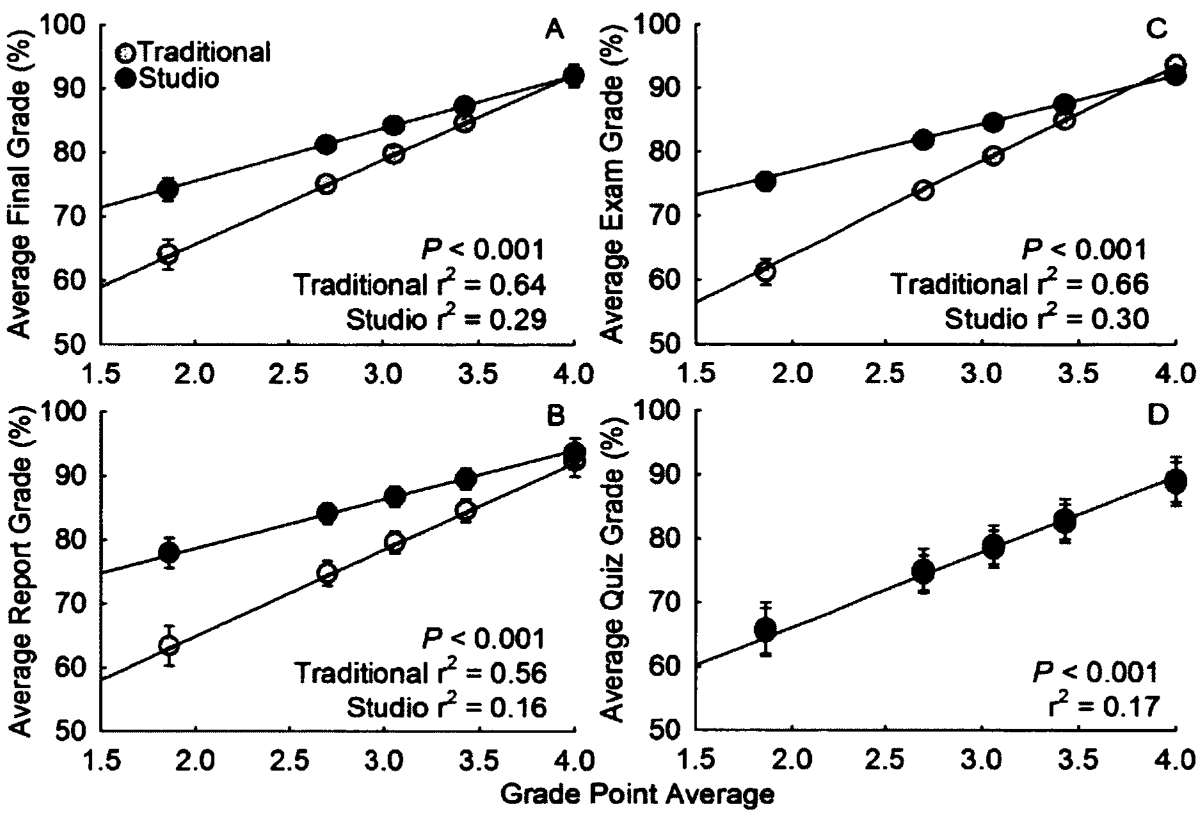


Figure 3.5. Average grade by grade point average (GPA) and course structure for final grade (A), reports (B), exams (C), and quizzes (D). Data points are the modeled least square means with standard error bars at minimum, 25th percentile, mean, 75th percentile, and maximum GPAs. The r^2 and regression lines are from regressions fit to a scatter of individual data points. Studio grades were higher than traditional grades for GPA ≤ 67th percentile (final grade), 77th percentile (reports), and 75th percentile (exams). N = 170.

CHAPTER 4

EXPLORING CONNECTIONS BETWEEN STUDENT PERSPECTIVES AND WAYS OF KNOWING IN A STUDIO-STYLE SCIENCE COURSE

Abstract

Despite a large body of research showing that lectures are not the most effective mode of learning, lecture-based courses continue to dominate undergraduate education. Student learning has been shown to improve in studio-style courses that integrate lecture and lab sessions into one unit and incorporate active learning strategies that require students to apply what they are learning via activities, thinking about what they are doing, and sharing their ideas with their peers and instructors. Less research has been done utilizing interviews to gain an in depth understanding of students' perspectives on course modifications, and few if any studies have explored the role intellectual development may play in shaping students' perspectives in such contexts. This study took place in the context of an introductory soil science course that had recently been re-structured into a studio-style structure where the lecture and lab had been combined and integrated with active-learning strategies. The primary objectives of this research were to 1) understand students' perspectives on their experiences in a studio-style course, and 2) determine whether understanding students' epistemological development can help understand their perspectives on their experiences. I conducted initial and exit interviews with 20 students to access their prior experiences and perspectives on the studio course and forty-nine students completed a questionnaire designed to access their epistemological development (Measure of Epistemological

Reflection (MER)). Interpretation and analysis of students' interview responses revealed four aspects of the studio structure that stood out the most to students: active learning (doing, thinking, sharing), integrated nature of the course (learning then doing, better for schedule, new experience), community (meeting people, approachability of instructors, comfortable, fun), and variety (learning methods and assessment methods. In particular, students attributed enhanced learning to: sharing, doing, thinking, learning then doing, variety of learning methods, and spacing/repetition. Most students exhibited absolute (16) or transitional knowing (25), while far fewer exhibited independent knowing (7), and only one student was found to exhibit contextual knowing. Comparing students' responses from the MER and initial interviews to their responses during the exit interview revealed some evidence that the studio structure may help promote epistemological growth. However, a few students clearly did not receive enough support to balance the challenge of the new structure. While there are areas where the course could still be improved (i.e. choice of assessments, better facilitation of instructor-student interactions, incorporating more opportunities for individual work and reflection), Studio Soils was largely successful at integrating active learning, spacing, and variety of learning methods into a studio-style learning environment. Recommendations for ways to improve the course to provide more support for some students are described.

Introduction

Lecture-based courses are the most common learning environment encountered by undergraduate students. However, lectures have been shown to be an ineffective mode of learning. A recent meta-analysis of 225 studies on undergraduate classes in science, technology, engineering, and mathematics courses showed that student performance on exams and concept inventories were lower and the likelihood of failure was higher in traditional lecture-based courses compared to courses that employed active learning strategies (Freeman et al. 2014). Such strategies require students to apply what they are learning in the classroom by doing activities, thinking about what they are doing, and sharing their ideas with their peers and instructors (Bonwell and Eison 1991, Meyers and Jones 1993, Armbruster et al. 2009). In the sciences most lecture-based courses are accompanied by a separate lab section where students are able to apply their learning; however these lab sessions are typically days (and in some cases weeks) ahead of or behind the lecture. Studio-style classes attempt to better integrate lecture and lab components by combining them into blocks of activity-based instruction; rather than three hours of lecture and two hours of lab per week, studio classes typically meet 2-3 times per week in 2-hour blocks (Beichner et al. 2007).

Research on courses that have implemented active-learning strategies and/or have been modified into a studio structure that goes beyond assessing student performance to address how such modifications might be received by the students themselves have shown mixed results where some students had positive attitudes toward the class structure and/or particular components, while others reacted more negatively. Positive reactions include beliefs that the use of active learning methods helped students learn course material (Ebert-May et al. 1997, Kovac 1999, Walker et al. 2008), made courses less intimidating and/or created a sense of trust (Ebert-May et al. 1997, Kovac 1999, Bull and Clausen 2000, Walker et al. 2008), meant the class was hard but rewarding (Oliver-Hoyo and Allen 2005), and made the learning environment more fun (Ebert-May et al. 1997, Oliver-Hoyo and Allen 2005). Negative reactions include a dislike of working in groups and/or preference for lecture (Dori and Belcher 2005, Armbruster et al. 2009), concern that active-learning exercises did not always culminate in being told the correct answer (Walker et al. 2008), complaints that group projects created more work for students (Bull and Clausen 2000), and frustration with the newness/unfamiliarity of an active-learning approach (Udovic et al. 2002). In some cases, early resistance to active-learning strategies had dissipated by the end of the course (Berry and Sharp 1999). Interestingly, while none of these studies explore students' views on the nature of knowledge (epistemology), in some cases students' responses suggest that epistemology may be an interesting factor related to student perspectives. For example, students' concern with knowing the right answers reported by Walker et al. (2008) suggest a belief that knowledge is certain and absolute. In contrast, student responses to a prompt on "what is learning" reported by Barry and Sharp (1999) included intake and memorization of information, gaining new knowledge or using what one already knows in a different way, and a process of discovery where new knowledge is linked to old; these responses suggest a range of views on the nature of knowledge. In addition, Udovic et al. (2002) postulated that some of the negative reactions to active learning could have been related to some students seeing the "world in black and white" (knowledge is certain and absolute) and suggested a possible connection to theories of cognitive development (such as those of Perry 1970 and Belenky et al. 1986).

Because most college science classes are taught in the traditional lecture-based format with a separate lab, the studio style of teaching and learning is a new experience for most students, and students may therefore be resistant to modes of teaching and learning that run contrary to these experiences, particularly if they have internalized these experiences into a belief system. My objectives were to 1) gain a better understanding of students' perspectives on their experiences in a studio-style course, and 2) determine whether understanding students' epistemological development can help understand their perspectives on their experiences. More specifically, this study addresses the following research questions: 1) What aspects of Studio Soils stand out most to students?; 2) What aspects do students' identify as being most beneficial for their learning?; 3) Are there similarities/differences in how students experience the course that can be explained by similarities/differences in their epistemological development?; and 4) Is there evidence of epistemological growth from the beginning of the semester to the end?

Theoretical Overview

The beliefs and theories that individuals hold about the nature of knowledge and knowing constitute their 'personal epistemologies' (Hofer and Pintrich 1997, Hofer 2004) or 'ways of knowing' (Belenky et al. 1986, Baxter Magolda 1992). Studies seeking to understand individuals' epistemological development are therefore concerned with understanding how those concepts about knowledge and the way people develop, evaluate, interpret, and justify knowledge, change with time and experience. Prior research on the relevance of epistemological development to education has shown that there are important implications for teaching and learning. Studies have shown that the beliefs students hold about the nature of knowledge can affect learning and performance; examples include reading comprehension (Schommer 1990), mathematical text comprehension (Schommer et al. 1992), information-seeking behavior (Whitmire 2004), and final grades (Tolhurst 2007). Studies have also shown that differences in learning experiences (Zorn et al. 1995), learning environments (Katung et al. 1999, Marra et al. 2000) and/or teaching strategies (Brownlee et al. 2001) can influence epistemological development.

Epistemological development is an important component of this study because the Studio Soils learning environment differs from the 'traditional' learning environments (lecture or lecture with a separate lab) that Studio Soils students had typically experienced. I therefore expected that this learning environment could put students out of their comfort zones and into a situation where their beliefs about how they learn, and thus about knowledge and knowing would be challenged. While this research focuses on Baxter Magolda's (1992) epistemological reflection model, it is important to note that her model was influenced by preceding theories of intellectual development, most notably Perry's scheme of intellectual development (1970) and Women's Ways of Knowing (Belenky et al. 1986).

Perry's scheme of intellectual development. The foundations of most models of epistemological development in adults can be traced to Perry's (1970) scheme of intellectual development. Perry conducted a series of open-ended interviews from 1954-1963 with male Harvard students. He used these volunteer interviews to map a scheme of ethical and intellectual development based on sequential interpretations that the students made of the world. Perry's scheme has nine 'static' positions that fall along a continuum: dualism, multiplicity, relativism, and commitment in relativism. Transitions between positions (movement along the continuum) occur as students encounter new experiences where their previously held beliefs no longer fit their new experiences. Dualism is the division of meaning into two realms, such as right versus wrong, black versus white, good versus bad. Knowledge in this position comes from authority figures, so students exhibiting dualistic ways of knowing tend to be passive learners, dependent on authority figures to teach them the 'right' answers. A student will move towards multiplicity as they begin to recognize that authorities may not have all of the answers and that not everything is known, and into relativism as they understand that truth is relative and meaning depends on context (Perry 1970 and 1981). One of the major criticisms of Perry's scheme is that it was developed from interviews with a very narrow segment of the population, and in particular was developed using interviews from primarily male students.

Women's ways of knowing. Belenky et al. (1986) conducted an epistemological development study of women, by women. They chose to use only women because they felt that "the male experience has been so powerfully articulated that we believed we would hear the patterns in women's voices more clearly if we held at bay the powerful templates men have etched in the literature and in our minds" (9). They compared their findings on women's thinking to Perry's scheme and found that for the women in their study, women's thinking didn't fit very neatly into Perry's scheme. They grouped their findings into five ways of knowing (though unlike Perry's scheme they weren't on a continuum). Silence is characterized by isolation and all power was placed with authorities; no participant in their study with college experience exhibited silence. Received knowing is similar to Perry's dualisim in that there is a belief that all knowledge is right or wrong, authorities know the answers, and the role of the student is to memorize what authority tells them. However, while some of Perry's dualistic knowers were outspoken and confrontational with peers, received knowers tended to feel alienated from authority figures and were more likely to commune with peers. Women who exhibited subjective knowing rely on personal knowledge and intuition because they have rejected authorities and peers as valid sources of knowledge. In contrast to subjective knowing, where intuition prevails, procedural knowing is characterized by an adherence to analytical methods. In constructed knowing intuition, authorities, and peers are all acknowledged as valid sources of knowledge. All knowledge is recognized as contextual and the knower is vital in constructing knowledge.

The model of epistemological reflection. Baxter Magolda's model of epistemological reflection is grounded in both Perry's scheme and Women's Ways of Knowing and outlines four ways of knowing (absolute, transitional, independent, and contextual) across six domains within education (decision making, role of learner, role of peers, role of instructor, evaluation, and the nature of knowledge). Absolute knowers view knowledge as certain and obtain knowledge from an authority figure. Transitional knowers begin to see some knowledge as uncertain, even as some knowledge remains absolute; they still rely on authority for certain knowledge but begin to appreciate themselves and their peers in uncertain areas. Students exhibiting independent knowing see all knowledge as uncertain and perceive no basis for making decisions: everyone has a right to their own beliefs and authority figures are no longer seen as the only valid source of knowledge. In contextual knowing, knowledge remains uncertain but students are able to come to a decision on the basis of evidence in context; rather than relying on authority, contextual knowers show appreciation for experts, who may be instructors or peers (Baxter Magolda 1992). Note that relativism (Perry 1970), constructed knowledge (Belenky et al. 1986), and contextual knowing (Baxter Magolda 1992) are essentially identical.

Within each way of knowing (except contextual), Baxter Magolda identified gender-related patterns. Within absolute knowing she identified a receiving pattern and a mastery pattern. Students showing the receiving pattern (more women than men) tended to emphasize more passive listening and recording and comfort in the classroom, while students showing the mastery pattern (more men than women) preferred a more interactive, verbal approach. Within transitional knowing, students' using the interpersonal pattern (more women than men) preferred interactions that fostered a sense of connecting with others: they enjoyed "collecting" the ideas and views of their peers and tended to seek rapport with their instructors. In contrast, impersonal students (more men than women) tended to prefer interactions with instructors and peers that forced them to think (e.g. an exchange of ideas via debate). Within independent knowing, students using the interindividual pattern focused both on thinking for themselves and on engaging in the views of others, though engaging in the views of others was more prominent. In contrast, while the students exhibiting the individual pattern of knowing valued interchange between themselves, their peers, and instructors, they tended to focus more on their own independent thinking. The gender-related patterns that appeared in each of these first three ways of knowing converged in the contextual way of knowing.

In addition to one-on-one interviews, the current study uses Baxter Magolda's (1992) measure of epistemological reflection (MER) to help understand students' perspectives on their experiences in the studio course. I focus on Baxter Magolda's epistemological reflection model primarily because her work represents an "integration and enhancement" (Evans et al. 1998, p. 160) of the work of Perry (1970) and Belenky et al. (1986) and because the model was developed from interviews with both male and female students. An additional advantage of using Baxter Magolda's model is that she developed a pencil-and-paper essay style questionnaire that can be administered to students as a way of accessing their ways of knowing and yields a rich qualitative data set that is complemented by one-on-one interviews. This Measure of Epistemological Reflection (MER) also focuses on six domains of education: decision making, role of learner, role of instructor, role of peers, evaluation, and the nature of knowledge. Three of these were particularly relevant to this study (role of learner, role of peers, and role of instructor) because interactions amongst a student, his/her peers, and the instructors in a studio-style course are quite different from traditional lecture-based courses.

Assumptions. I hold the assumption that students make their own meaning of their experiences in education. The meanings students make of their experiences are influenced by their previously held views, by the views of others (peers, professors, etc.) that they encounter, and by the context in which the experience takes place. This notion that the meaning we make of our experiences cannot be separated from the social context in which we are brought up in, and in which the experiences occur, is a fundamental assumption of social constructivism (Crotty 1998). Thus, I also recognize I cannot separate myself and all my experiences, choices, interpretations, etc., from the inquiry, and that this study is bound by the time and context in which it occurred (i.e. a single semester of Studio Soils in the fall of 2011). This narrow context does make it difficult to generalize the findings to other contexts, but I have included, within this chapter and the preceding chapter, a detailed description of the context in order to aid others in determining the extent to which these findings are transferable to other contexts.

Method

Setting

The University of New Hampshire (UNH) is a public land-, sea-, and space-grant university with a total undergraduate enrollment of 14,761. The Department of Natural Resources & the Environment, housed within the College of Life Sciences and Agriculture, integrates social and natural resource sciences and offers a Bachelor of Science degree with seven majors. Currently there are 395 students enrolled in the department. This research took place in the fall 2011 semester of Studio Soils (formerly Introduction to Soil Science), a sophomore level introductory soils science course for natural resource majors (though the course is open to all students at UNH and there are usually a few non-majors enrolled each semester). In 2010 the course was modified into a studio structure where the lecture and lab portions were integrated into two 2-hour long sessions per week. Because there is currently no studio-capable room on the UNH campus able to accommodate 70 students, the course was taught concurrently in two rooms.

To align with principles of active learning (students apply learning by doing, thinking, and sharing; Bonwell and Eison 1991, Meyers and Jones 1993) and following the examples of others (e.g. Beichner et al, 2007), the studio course was designed to incorporate hands-on activities, data analysis, short writing assignments (group and individual), and small group discussions (students worked in groups of three and group composition was switched at the beginning of each of four units). A typical class was comprised of one or two mini-lectures (approximately 15 minutes in length) separated by periods in which students were engaged in one or more of these activities; however, some sessions leaned more heavily toward lecture, some more heavily toward group activities, and some took place entirely in the field. In addition to implementing active learning strategies into a studio structure, the course was organized into four units based on soils interactions with earth system spheres (lithosphere, biosphere, hydrosphere, and atmosphere) and some topics (i.e. soil taxonomy) were spaced out across all four units in the studio course. More details on course objectives, current studio structure, and the re-structure from a traditional lecture course with separate lab to the studio structure are described in Chapter 3 of this dissertation.

Instructors/researchers

The course was co-taught by a primary professor (had taught the class at UNH since 2002) and I (had acted as a teaching assistant for the class from 2006-2008). We worked together to modify the class from the traditional lecture-based structure with a separate lab to the current studio structure. One teaching assistant was also present for each of the two sections; one of whom had been a teaching assistant for the course the previous year and the other of whom had no prior experience in the soils class but was an experienced teaching assistant in the wildlife program.

While circumstances necessitated my presence in the classroom, my role as an instructor was minimized to the extent possible; while I was present to give mini-lectures and facilitate group activities during class, I had no role in grading students' coursework or any influence on their final grade in the course. In addition, neither the primary professor nor the teaching assistants had any access to research data during the semester, and they never had access to participating students' identity, interview recordings, full transcripts, or the handwritten Measure of Epistemological Reflection (MER).

Participating students

Institutional Review Board (IRB) approval was obtained for this research (IRB #5243; Appendix 7) and informed consent was sought from all students through the use of consent forms for participation in a research study involving human subjects. Demographic data was collected from students by way of a questionnaire (Appendix 5) distributed during the first week of class. Of the 70 students enrolled in 2011, 20 participated in the interviews; seventeen of the interviewees also completed the Measure of Epistemological Reflection (MER). An additional 32 students completed the MER but did not participate in the interviews. Based on one-sample *t*-tests (GPA and final grade) and contingency table analyses (gender, year in school, and major), the subset of students who completed the MER and the subset of students who participated in interviews captured the variability of the full 2011 cohort with regards to gender, year in school, GPA, and final grade (Table 4.1). With regards to major, however, none of the nine non-Natural Resource majors were amongst the MER or interview participants. (Table 4.1; demographics for each of the 52 students who completed the MER and/or participated in interviews can be found in Appendix Table A4.1).

All participating students were majoring in a natural resources field or agricultural field and had extensive hands-on and outdoor field experiences. However, none of the students had prior college experience in a studio course (the only other studio course offered on the UNH campus is Studio Physics, which no participating student had taken), and so these prior hands-on/field experiences all occurred during lab sessions that were separate from the lecture portion of their classes. Thus, the studio course was a new experience for most students (one student had experienced a similar learning environment during high school). Transfer status is unknown for students who did not participate in interviews, but of the 20 interview participants, ten had transferred from a different university or from a different program within UNH, two had changed majors within the program, and the remaining eight students had been at UNH in their current program of study since their first year. All names included in this dissertation are fictitious.

Data collection

Measure of Epistemological Reflection (MER). The MER is a pen-and-paper essay-style questionnaire broken into six domains (all in education): decision making, the role of the learner, the role of the instructor, the role of peers, evaluation, and the nature of knowledge. Each domain consists of an initial question related to learning preferences (e.g. Do you prefer classes where students do a lot of talking or where students don't talk very much?), followed by three or four probe questions to elicit detail on students' reasoning (e.g. Why do you prefer the degree of student involvement/ participation that you chose above? What do you see as the advantages/ disadvantages of your choice?). The full MER can be found in Baxter Magolda 1992. Permission to use the Measure of Epistemological Reflection (MER) was obtained from Marcia B. Baxter Magolda prior to administering it to students (Appendix 4). At mid-semester of fall 2011, all students were given the opportunity to complete the MER during class time. Students received class participation points for completing the MER and students who did not want to participate were given a short in-class writing assignment for which they received the same amount of points. Students were given forty-five minutes to complete the MER, and no student required the full amount of time. While I was present during this period all other instructors left the classroom.

Interviews. All students were given the opportunity to participate in initial and exit interviews by indicating their interest on a demographic questionnaire given on the first day of class. Interested students were contacted via email to schedule initial interviews, which were conducted within the first three weeks of the semester; all initial interviews were completed before students filled out the MER. Initial interviews were approximately thirty minutes in length; the primary purpose was to access students' prior experiences in their program of study, but I was also interested in these interviews as an additional way of accessing students' ways of knowing. The initial interviews were thus semi-structured, consisting of five primarily open-ended questions related to prior experiences with three additional questions specifically probing for their views on the roles of instructors, peers, and the learner; the interview protocol I developed (Appendix 5) was modified from the protocol used by Baxter Magolda (1992). The use of interviews as the primary data was based on the view by many naturalistic researchers (e.g. Perry 1970, Belenky et al. 1986, King and Kitchener 1994) that interviews provide the most accurate source of information. While interviews were semi-structured, an emphasis on open-ended questions was used in order to allow the students' viewpoints to be heard with minimal influence from the researcher. All students who participated in the initial interviews were contacted three weeks before the end of the semester to schedule an exit interview.

Exit interviews were approximately forty-five minutes in length and focused on students' experiences in Studio Soils. Exit interviews began open-ended ("What stood out the most from your experiences in Studio Soils?") but included four to six additional questions focused on identifying aspects of the course that could be improved (i.e. "If you could change something about the way this course was taught, what would you change and why?"; see Appendix 5 for interview protocol). All interviews were audio recorded except for two students who did not give permission to record their interviews; in these cases I took notes during the interview and typed up my notes immediately following the interview.

Data analyses

Interpreting the Measure of Epistemological Reflection. The MER interpretation process is described in detail by Baxter Magolda (2001). Briefly, each student's full response across all domains was read and the central reasons for the student's thinking for each domain were identified. These reasons were then interpreted within the context of the epistemological reflection model by comparing them to the ways of knowing described by Baxter Magolda (1992). In general, if a student's response showed no evidence of uncertainty they were classified as absolute knowers; if their response clearly showed that they viewed some knowledge as certain and some as uncertain they were classified as transitional knowers. If a student's response showed that they viewed all knowledge as uncertain and they emphasized thinking for oneself and/or the view that everyone has a right to their own beliefs, they were classified as independent knowing. If their response showed that they viewed all knowledge as uncertain but described making decisions in a given context based on available evidence, they were classified as contextual knowing. These distinctions were typically most obvious in students' responses on the role of learner domain (where they described their preference for facts or theory) and the nature of knowledge domain (where they described their process for making a choice between two explanations), though students responses to all six domains were used to make the final decision.

Once a way of knowing had been identified, the interpretation was extended to consider gender-related patterns. Within absolute knowing, if a student emphasized a more verbal, interactive approach to learning (asking questions, debating), they were classified as mastery pattern and if they described a more internal approach (listening and taking notes), they were classified as receiving pattern. Within transitional knowing, if a student emphasized working alone, made a distinction between understanding and memorizing, and/or used logic or research to choose between competing explanations, they were classified as impersonal pattern; if they focused more on relationships with others, being exposed to new ideas, and hearing other's views they were classified as interpersonal pattern. Within independent knowing, if a student emphasized everyone having their own beliefs and valued instructors who encouraged independent thinking, they were classified as individual pattern; if they focused more on connections with others and exchanging views, they were classified as interindividual pattern.

Finally, once the way and pattern of knowing exhibited by a particular student was identified, excerpts from students' initial interviews were examined to back-up the interpretation. In particular, the initial interviews elicited students' views on the roles of instructors, peers, and themselves as learners (only applicable for the 17 students who participated in interviews).

Transcribing and coding interviews. All interviews were transcribed by carefully re-creating the verbal and non-verbal material. Once interviews were transcribed, interesting passages were identified and bracketed. These passages were imported into a software program (NVivo 10) for coding. The data were analyzed through qualitative analysis (Merriam 2009, DeCuir-Gunby et al. 2011). Open data-driven coding was used for the first three interviews, highlighting anything that stood out and assigning tentative codes. After coding the first three interviews, these codes were examined and organized into themes (axial coding). These themes and codes were then worked into a preliminary conceptual model for understanding student experiences in the course. This process was repeated every three interviews, refining the themes and conceptual model, until no new themes were added (approximately half of the interviews had been coded). The remaining interviews were coded using these codes and themes. After all interviews were coded and all MERs had been interpreted I continued to refine the conceptual model by comparing students' initial interview and MER responses to their exit interview responses, looking for specific references students made to learning and for connections amongst their experiences, self-described learning, and ways of knowing. I also expanded my analysis by looking for additional factors that might help to better understand students' experiences in Studio Soils (theory-driven and structural coding).

Findings

Conceptual model of the Studio Soils experience

The process of interpreting students' interview and MER responses led to the creation of a conceptual model of the Studio Soils experience: students' perspectives on their experiences and their learning make up the Studio Soils experience, while their ways of knowing, prior experiences, and current competing commitments influence this experience. Participating in studio soils may help promote epistemological growth (feedback to way of knowing) via a balance of support and challenge (Figure 4.1). This conceptual model is presented as a framework for interpreting the findings, all of which are described in more detail below.

Aspects of Studio Soils that stood out

Students' responses to the question "What stood out to you the most from your experiences in Studio Soils?" can be broken primarily into four broad categories, each of which includes two to four subcategories: active learning (doing, thinking, sharing), the integrated nature of the course (learning then doing, better for their schedule, new experience), community (meeting new people, approachability of instructors, being comfortable, having fun), and variety (learning methods, assessment methods; Figure 4.2; see Appendix 4 for the codebook of definitions and examples of categories and subcategories).

Not everything that stood out to students can be linked to student learning because some of what they spoke about related more to enjoyment or convenience than learning. However, most students (95%) did specifically explain how one or more of the above aspects helped them learn (Figure 4.3). Active learning (applying learning by doing, thinking, and sharing) was linked to improved learning by 16 students (80%). Ten students (50%) said that sharing ideas and/or perspectives with other students helped them learn. For example, Julie thought talking about the material with other students helped her learn: "...in class we had to answer questions together and talk about it – I think just having time to talk about it [is more helpful than having] a teacher standing up there asking questions and...whoever knows the most is answering the question." Six students (30%) spoke of benefits related to thinking more about the material. For example, Ingrid described how being forced to think about things help her understand how everything connected:

> That was a really key part of the class, is understanding the relationships and how everything was connected and dependent on one another, and that was really great because [the instructors] did a great job at not answering the questions so you could have the answer, and making you think about it, and sometimes it would be like "come on!" you know, but...it was great because I had to think of different ways to think about it, and that was really a huge part of the class that I liked a lot.

Five students (25%) said applying learning via hands-on lab and field activities helped them learn, as for example when Laura said:

> After the class I'm really gonna enjoy...going outside, and if I see a little pit and I see all the horizons in it, I can be like "I know what that is, and what that is" you know? Because I can see it on a daily basis I know that I'll retain it a lot better, so I'm excited for that, and I know that I'll be able to use that, absolutely, in the future.

In addition to active learning, five students (25%) explicitly linked the integrated nature of the class (learning then doing) to improved learning, as for example when Celia said: "It was helpful by literally talking about it and then immediately doing it...it was a lot more helpful and it made sense." Four students (20%) said that the use of a variety of learning methods during class helped them learn. For example, Owen said:

> I think that the varied nature of the course was actually more helpful than I originally thought it was going to be because...some of the more memorization-based things that we learned I picked up better in lectures, some of the [skill-type things]- --that's something that you need to actually do...and then having the worksheet-based stuff for other types- --having a little bit of every sort of learning in there helped.

While not one of the aspects of the course that stood out to most students, four students (20%) did specifically link spacing and repetition throughout the semester as helping them to learn soil taxonomy in particular. For example, Ingrid said: "I really liked how the twelve soil orders and the whole...taxonomy behind how it's all constructed, I like how that was presented throughout the entire semester and it was really clear and organized, and I didn't feel overwhelmed with all the subsurface...characteristics...[and] the horizons."

Downsides of active learning and the studio structure

While students primarily spoke positively about the four components described above, almost all of the students (95%) mentioned one or more downsides to the studio course (Figure 4.4). Sixteen students (80%) spoke about having some issues working with peers, typically related to unequal contribution. However, most of these students described these issues as being minor and felt the positive aspects of working with peers outweighed the negatives; only four students (20%) felt that working with peers sometimes hindered their learning and only Jake felt that working in groups hindered his learning more than it helped. While Jake did say that sometimes working in groups can be helpful ("there's times where if I need a little bit of help I can just ask someone in my group to maybe explain it a little and vice-versa"), he primarily felt that working in groups during class time prevented him from learning as much from the instructors:

> I find that I either end up doing a lot of the work singly, or I end up riding other people's coattails where I don't necessarily understand something ...But that wasn't just for this class in particular, I mean that's just group work as a whole, but seeing how this class is a lot of group work, I can find that probably happen a lot. Also...kind of what I like is just hearing from a professional with a lot of experience, whether it's a grad student or a doctor, instead of just kind of having a study group format in the classroom, I feel like that could be done outside of class, or something. I just don't feel like I get everything I had wanted out of it, with questions and stuff.

In addition to occasional problems arising due to the high amount of group work, nine students (45%) expressed a desire for more field work. While this appears to be something most students' desire in all their classes, not just in Studio Soils, four students (20%) did say that the level of field work in Studio Soils was less than that typical in other classes. In contrast, six students (30%) expressed a desire for more lecture.

Two students (10%) felt that active learning that emphasized working with peers led to a lack of interaction with the instructors, and one student (Philip) felt that even though instructors attempted to engage with students, his peers were perhaps afraid to speak up, which he felt inhibited him from speaking up as well:

> It stifles <u>me</u> to ask questions- --that people don't ask questions as much, you know sometimes...you guys would ask a question to the class, and it's just like blank faces, like they're afraid to speak or something, and then it's like, "Well I don't want to be the only one who talks 'cause then I'll look like an idiot or something if I say something wrong."

Finally, three students (15%) felt that because of the variety of learning methods, trying to squeeze everything in led to time constraints and feeling rushed.

<u>Competing commitments influence on students' experiences and learning</u>

Some of students' negative feelings about the course may be partially explained by competing commitments. Seven students (35%) described situations where commitments such as work, extracurricular activities, or other classes affected their experiences, learning, and/or performance in Studio Soils. For example Anna's view that the length of class was sometimes difficult was a least partially explained by how this fit with her other classes: "Sometimes it's hard for two hours...especially 'cause I have the nine to ten, and then this, and then I have another class and then I have an hour break and then I have a three hour lab on Monday's so I was like 'Aaaah, a two hour class!'" Zach also explained how being overwhelmed by work for other classes affected how he prioritized work for Studio Soils: "Because I just had all of this work and all of a sudden, you know, I'd forget about this little thing called soil science, and oh a report on this due....I had so much work that it was you know- --quizzes, soil sciences, it was like a low priority of a low priority." Elena described prioritizing Studio Soils below a more difficult upper level class she was taking at the same time: "I'm also taking limnology...and maybe it's just me, but it's so complex and hard, but I feel like I'm doing better in it, almost, just 'cause I know that I have to do it and stay on top of it, whereas like, I don't know, soils maybe got put on the back burner a couple of times just because of that." On the other hand, Ingrid explained that she liked that the Studio Soils collaborative activities were done during class time because she didn't have to worry about trying to schedule time for out-of-class projects:

> Those I thought were great too because they were in class...I don't know if professors are aware of how difficult it is for students to do a group collaboration project, especially one where it's a major component of your grade, because you have such limited time availability...students have other commitments like work or things like that, and it's just not right to do that because...you fill out a schedule and there's three or four hours you can meet....So the in class work was good, with the groups, I liked that.

Ways of knowing

Of the forty-nine students who completed the Measure of Epistemological Reflection (MER), 16 (33%) exhibited absolute knowing (all knowledge certain, instructors have answers, learner obtains answers from instructor), 25 (51%) exhibited transitional knowing (some knowledge is certain and some uncertain, emphasis on understanding over memorization), seven (14%) exhibited independent knowing (all knowledge uncertain, all beliefs valid/equal, independent thinking valued), and one (2%) exhibited contextual knowing (all knowledge uncertain but you can make choices based on evidence in context; Figure 4.5).

Within absolute knowing, six students (37.5%) employed the absolute mastery pattern (verbal interactive approach) and ten (62.5%) employed the absolute receiving pattern (internal approach). Within transitional knowing, 16 students (64%) employed the impersonal pattern (individually focused, emphasized understanding over memorizing) and nine (36%) employed the interpersonal pattern (focus on relationships with others, exposure to new ideas and hearing other's views). Within independent knowing, five students (71%) expressed the individual pattern (everyone has their own beliefs, focus on thinking for oneself) and two (29%) expressed the interindividual pattern (focus on interactions and connections with others; Figure 4.5). More men than women exhibited the mastery, impersonal, and individual patterns, and more women than men exhibited the receiving and interpersonal patterns; the interindividual pattern was represented by one man and one woman (Figure 4.5; see Appendix 4 for a narrative description of the ways and patterns of knowing expressed by Studio Soils students).

The sample of students who completed the MER and participated in interviews included five absolute knowers (all receiving pattern), nine transitional knowers (four impersonal, five interpersonal), two independent knowers (one individual, one interindividual), and one contextual knower. Because of the small sample size, and because not all patterns within ways of knowing were expressed by students in the interview sample, for the purpose of looking for connections between patterns of knowing and student perspectives, the patterns were grouped into two pattern types: 'separate' and 'connected' (after Belenky et al. 1986). Students who exhibited the mastery, impersonal, or individual patterns were grouped into a 'separate' pattern type (externalize the learning process and focus on themselves), while students exhibiting the receiving, interpersonal, or interindividual patterns were grouped into a 'connected' pattern type (internalize the learning process and focus on relationships with others).

Connections between student perspectives and ways of knowing

In most cases, references to each of the aspects that stood out to students were made by students representing all four ways of knowing and both pattern types. Because there were only two independent knowers and one contextual knower within the sample of students who participated in interviews and completed the MER, and because there were more than twice as many students expressing one of the 'connected' pattern types as expressing one of the 'separate' pattern types (eleven and five, respectively), it is difficult to determine if there are strong connections between student perspectives and their ways of knowing or pattern type. Keeping that in mind, there were some cases (variety of assessment methods, thinking, community) where tentative relationships emerged. Amelia and Ingrid were the only two students who expressed an appreciation for the variety of methods used to assess their learning, which is a characteristic of transitional knowing, and in particular the interpersonal pattern ('connected' type) that both Amelia and Ingrid express. No absolute knower explained 'thinking' about the material as being beneficial for their learning and most (five of six) who connected thinking to improved learning expressed one of the 'separate' pattern types. While students from all ways of knowing and both pattern types expressed some appreciation for a sense of community, all of the students who specifically emphasized comfort in the learning environment expressed one of the "connected" patterns. For example, Maddie and Jason, who both expressed the receiving pattern within absolute knowing, spoke about not always feeling comfortable enough to speak up during class. Ingrid, who expressed the interpersonal pattern within transitional knowing, also spoke strongly of the importance of being comfortable, most directly when talking about interactions with instructors. Philip, who expressed the interindividual pattern within independent knowing, spoke about how he sometimes felt "stifled" when other students were reluctant to engage with the instructors. Additionally, within community, most students who mentioned the approachability of the instructors (six of seven) and meeting new people (five of eight) expressed one of the 'connected' pattern types.

In some cases, even if the same aspect stood out to students across ways of knowing and/or pattern type, their reasoning about why it stood out and/or how it improved learning could potentially be explained by epistemology. For example, spacing and repetition were linked to learning soil taxonomy by Maddie (absolute), Ingrid (transitional), and Thomas (contextual). Maddie explained that soil taxonomy would be what she would most likely take away from the class because there was so much memorization involved (i.e. learning equated with memorization and remembering). Ingrid focused more on spacing, clarity and organization as teaching methods that reduced anxiety and promoted understanding. In contrast, Thomas made the distinction that repetition is an appropriate and useful tool for "memorizing for the sake of it, or being able to identify something" but explained that it is not as useful if you are analyzing or quantifying an idea (i.e. context determines appropriate learning method).

Sharing (workload, ideas, perspectives) was also something that stood out to students across ways of knowing, but absolute knowers were the only ones who emphasized sharing the workload and were more likely to equate sharing with talking in order to get the right answer. While transitional knowers sometimes spoke of talking to get answers they were more likely to add that group discussions allowed them to hear new ideas that they had not thought of on their own and hear from students with different viewpoints. The two independent knowers focused more on sharing views (as opposed to just hearing them) as for example when Philip explained the learning process as a "two-way street." Thomas, the only contextual knower, spoke of sharing perspectives ("I felt like that was really important to the whole learning process, to understand your peers perspectives on things as much as your own") and shifting between attitudes and different ways of viewing things.

Ways in which the Studio structure may promote epistemological growth

"Sneaky" learning. Two students (Anna and Celia) spoke directly about what I am calling "sneaky" learning. Sneaky learning occurred when a student realized they had learned something only when confronted with an assessment; it is associated with feelings of anxiety prior to assessment (because they do not feel they learned anything) followed by relief when they discover they actually had learned. While only two students (10%) spoke directly about sneaky learning, their description of this phenomenon suggests that the studio structure may promote student's epistemological growth by helping to diminish the role of authority and/or increase the role of the learner. Based on her initial interview and the MER, Anna viewed knowledge as absolute (right and wrong answers) and expressed the receiving pattern (preference for lecture, paying attention, and taking notes). Her description of experiencing sneaky learning was the first time (in interviews or MER) that she entertained the notion that she did not have to learn from lectures. While she still attributed her learning to the instructors ("sneaky teachers") and expressed a lot of confusion and uncertainty about how she actually learned, this experience has the potential to be a nudge along the path toward transitional knowing:

> There's something I thought was kind of weird, that before the exams I didn't feel prepared, and then we took the exams and the questions seemed really easy...I don't know before my exams...I freaked out, like "Oh my God I don't know anything!" and then you got the exams and it's like "Oh. I know this." I don't know if it was that it wasn't as much lecture, but I never felt like I knew everything, and then we got the questions and I was like "Oh wait, we did learn all this."...You guys are sneaky teachers I guess, I don't know....Maybe it was because you guys teach in the studio and not just lecture, but, I don't know. It was a weird- --it was a weird experience to have {laughs}. Yeah, you just don't seem like you're

> learning, maybe- --maybe that's what it is, 'cause they're not lecturing at you.

Celia described a very similar experience, but unlike Anna's belief that knowledge is absolute, Celia viewed some knowledge as certain and some as uncertain (transitional knowing) and expressed the impersonal pattern (preference for working alone and hands-on learning; emphasis on understanding over memorization). When describing experiencing sneaky learning, Celia focused on herself as a learner and did not mention instructors explicitly. Thus, for Celia this experience perhaps helped to distance her more from authority and elevate her own role as learner, which could potentially have nudged her towards independent knowing:

> It was actually really interesting I guess, the way it was set-up with the studio style. I felt like when it'd be time for an exam and I was like "I don't even know what I learned!" I don't know, I feel like I haven't memorized anything, there was nothing that I remember, but then I'd look at the study guide...and realize I knew everything on it, just from being immersed in what we were learning instead of having the ideas be drilled into my head over and over again. So that I guess stands out the most, is I really, all the time, didn't realize how much I had learned.

Expanded role of peers. While Anna and Celia were the only students who described experiencing "sneaky" learning, three other students (15%) did express changes in their views on the role of peers from the initial interview to the exit interview. Amelia's initial interview and MER revealed that she was in the early stages of transitional knowing, just beginning to feel comfortable expressing her own voice. At least one prior experience in a class where the professor fostered a comfortable environment helped her begin to express herself: "I mean he would talk a lot and give lectures but he'd also involve us – 'cause I'm shy and [I usually hate] a class that I'm sitting in where I'm like 'Oh my God please don't pick on me,' but he made it really fun, and he's really helpful, so I really liked his class." She thought that class also helped her with "critical thinking [and] being able to postulate my own ideas." Amelia also emphasized a preference for working on her own because she trusted herself more than other students: "If I could choose I'd rather do things on my own because I know that I can trust myself {laughs}, and I just always like my work better, I think that's like anyone." She did explain that "it does help to hear other students' ideas and points of view" but felt that this was difficult because: "I'm not like super outgoing...so group work's not super fun for me." By the end of the semester however Amelia's feelings about working with peers had changed considerably:

> Collaborating with a lot of my peers in the class, I think definitely stood out the most. I feel like not a lot of classes do that, unless you're in the lab, so I liked how that was integrated into the class, and how that was the whole purpose of it...I don't really do that in any of my other classes, so it's nice to actually talk to people that are within my major...Yeah I thought it was all helpful, because, I don't know, to hear what they had to think, and I don't know, not always just to have to like rely like- --'cause I mean honestly sometimes, I don't know like all the answers and stuff like that, so it's nice to like have them to help figure stuff out.

Amelia's emphasis on "knowing the answers" still indicates that she was exhibiting transitional knowing, but this change in perspective on the role of peers could indicate progress within transitional knowing further away from absolute knowing and moving closer toward independent knowing. In Amelia's initial interview and the MER, the importance of feeling comfortable in the learning environment came through strongly and so perhaps the aspect of the studio structure that was most relevant to her changing perspectives on peers was how it helped create a comfortable environment (and foster a sense of community):

> I really got to know a lot more of the people in the class, so that was good. And there were some times [when] kids that I'd previously had in other groups were in my new group, so even though I already had worked with them, not someone new, I still liked it, because we already had worked together and it was easy to talk to each other.

To a lesser degree Claire also shifted her perspectives on the role of peers. Based on her initial interview and the MER, Claire viewed knowledge as absolute (right and wrong answers) and expressed the receiving pattern (preference for lecture, paying attention, and taking notes). In her initial interview she focused primarily on negative aspects of working with peers, such as distracting her during lecture when she was trying to pay attention or situations where other students did not care as much about their work: "It's really difficult when you're in your group and people don't care as much as you might. And it's kind of frustrating because I'm obviously not going to do the whole project for everyone." When asked if any experiences had been helpful she did explain an experience where a successful group helped to share the workload:

> We would decide who did what in the group and everyone did it, and everyone knew what they were talking about and we helped each other ...so you know "You do this, and I'll do this, and you do that and we'll just get through it quicker."

During her exit interview Claire expressed a greater appreciation for working with peers, and while she still viewed peers as helpful for sharing the workload, she had expanded her description on the role of peers to include getting other's views and thinking about things in a different way: "I liked the group work, I know a lot of people didn't, but I liked it because you can always split the work load, and you can get other people's views on things, and it's like "oh, I didn't think about that" type a thing, so it is helpful. To me anyway." This expanded view on the role of peers could indicate a shift towards transitional knowing where hearing other's viewpoints becomes more important.

Stephen also expressed an expanded view of the role of peers from his initial interview to his exit interview. Like Amelia, Stephen's initial interview and MER revealed that he viewed some knowledge as certain and some as uncertain (transitional knowing), but in contrast to Amelia he expressed the impersonal pattern. In his initial interview Stephen focused primarily on peers as contributing (or in some cases not contributing) input to course projects. In his exit interview however he had expanded his view of the role of peers to include hearing new ideas: "Yeah, well you know you have new ideas from other people, and...yeah just new ideas from other people that maybe you didn't think of." In addition to an expanded view on the role of peers, Stephen also changed his opinion on his preference for lectures. In his initial interview he said:

> Okay, this is something that I did want to mention, when I first heard about this I thought it was a really good idea 'cause...lectures can be a little bit long, but so far in the course, I've kind of been missing the lectures a little bit. I don't know if it's gonna pan out over the whole year, it's kind of tough to say this early, but you know, I did want to mention that, we'll see how it goes.

By the end of the semester however, Stephen had changed this stance: "Well, I remember when we did this interview the first time I had said that I was missing some of the lectures but, I kinda found that after a while I really didn't. I think that the mini-lectures were just the right amount, and I actually like the format a lot, you know just being more interactive." Stephen's expanded view on the role of peers and decreased dependence on lectures (authority) could potentially indicate shifting more towards independent knowing.

Support and Challenge. Throughout all of the above descriptions on the potential for growth there is an underlying theme of support and challenge. The challenge of the studio structure was primarily that it was a new experience where students had to rely more on themselves and their peers than on the instructors; this challenge often manifested itself as feelings of stress and anxiety related to what was expected of them. However, for many students the sense of community fostered by peers and instructors acted as a support that balanced the challenge of the new experience. For students like Anna, Celia, Amelia, Claire, and Stephen, who all exhibited shifting perspectives, there appeared to be an appropriate balance of support and challenge: enough challenge to promote change and enough support to prevent the challenge from being overwhelming. However, there was at least one student who likely experienced more challenge than support. Jake keenly felt the stress of the new experience, which was exacerbated by feeling time constraints:

> A lot of the time you just kind of get agitated 'cause you've been there a while and you just start going through the motions, and you don't really understand what's going on and you're just trying to race through it and you just either give the answers that you think want to be heard.

Jake also expressed a strong preference for lecture and an inability to "break the mold" formed from prior experiences of "just being taught things." The strength of his prior experiences combined with such an imbalance of challenge relative to support may have prevented Jake from shifting beyond the transitional way of knowing. On the other hand, other students may not have experienced enough challenge. For example, Owen, who exhibited the independent way of knowing, for the most part did not feel that the coursework or his peers challenged him. He found the coursework to be too easy, particularly the research papers:

> I understand you guys have four instructors for seventy-two kids- --having something that's quick and easy is really good. And it's really hard to design things that are quick and easy <u>and</u> really intensive, thought provoking things as well. So I'm not going to say that you should <u>change</u> it, but I think that...there's really no rigor to these studies, and...I found that I could probably do the projects in...two hours, or so...you know it seemed like I could bang these things out real quick, it...didn't take a whole lot of thought, [the] writing process was quick and easy.

Even though Jake experienced more challenge and Owen experienced less challenge, both of their experiences involve an imbalance of challenge relative to support that may have prevented them shifting beyond their current way of knowing.

Discussion

I gathered data from one-on-one interviews and student responses to the Measure of Epistemological Reflection in order to better understand student perspectives on their experiences and to discover whether relationships amongst student perspectives and ways of knowing existed in the context of an active learning studio-style course. The research presented here was conducted specifically to address the following research questions: 1) What aspects of the studio course stand out most to students?; 2) What aspects do students' identify as being most beneficial for their learning?; 3) Are there similarities/differences in how students experience the course that can be explained by similarities/differences in their epistemological development?; and 4) Is there evidence of epistemological growth from the beginning of the semester to the end?

Active learning, the integrated nature of the studio structure, a sense of community, and the variety of learning and assessment methods were the aspects of the course that stood out the most to students. Students did not relate all of these aspects to improved learning, but many students directly attributed active learning (doing, thinking, and sharing), learning then doing, the variety of learning methods, and spacing/ repetition to improved learning. While students' self-assessment of learning may not be an accurate measure of learning that took place, as reported in Chapter 3, students in the studio-structure did outperform students in the traditional structure on research reports and exams; they also achieved higher final grades and were less likely to fail the course. Therefore, it is plausible that the components identified by students' as improving their learning may be responsible for the increased performance in the studio course relative to the traditional lecture-based course. In Chapter 3 I posited that the increased performance could be due to active learning, the studio structure, and/or changes in the way the material was presented (i.e. spacing). Based on students' perspectives, all three of these components played a role in improving learning; though active learning, and in particular sharing with other students, was identified by more students as being beneficial. Other studies on active learning environments that have reported on student perspectives have also shown that many students perceive sharing within small groups to benefit their learning (Ebert-May et al. 1997, Berry and Sharp 1999, Bull and Clausen 2000, Dori and Belcher 2005, Walker et al. 2008). Spacing (revisiting the same concept after a delay) has also consistently been shown to improve recall and learning (as discussed by Paschler et al. 2007, Kornell and Bjork 2008, and Mayer 2011).

This study took place in a sophomore level introductory class, and even though most students were absolute or transitional knowers, there were still at least seven independent knowers and one contextual knower in the class. This finding lends support to the idea that students across all stages of knowing are likely to be found in a given class, especially when there is likely to be a mix of class levels, ages, genders, transfer students, and/or non-traditional students. Within the smaller sample of 17 students who had completed the Measure of Epistemological Reflection and participated in interviews, I found a few potential connections between ways of knowing and perspectives on the course. While some aspects of the course stood out only to students of a particular way of knowing (i.e. varied assessment methods only mentioned by transitional knowers) or pattern type (i.e. emphasis on comfort in the learning environment only mentioned by students expressing one of the 'connected' patterns), other aspects stood out to students across ways of knowing (i.e. spacing), though their reasoning could sometimes be explained by their way of knowing. This suggests that the studio course as described here may have particular benefits for students expressing a given way or pattern of knowing but that it also has value for students expressing all ways and patterns of knowing. These findings highlight the importance of understanding and valuing students at all levels of development, which is one of the five instructional conditions of the Felder and Brent (2004b) model to promote intellectual growth. Their model of balanced instruction for science and engineering students combined theory related to intellectual development, learning styles, and learning approaches. In addition to respecting students at all levels of development, their model contained four other conditions: 1) variety and choice of learning tasks, 2) explicit communication and explanation of expectations, 3) modeling, practice, and constructive feedback on high-level tasks, and 4) student-centered instructional environment. In addition to students' explicitly mentioning variety of learning tasks and aspects of a student-centered instructional environment (doing, thinking, sharing), changes in the way several students viewed the role of peers along with two students' descriptions of "sneaky" learning lend support to the idea that a variety of learning tasks within a student-centered instructional environment can promote epistemological growth. However, because I did not conduct a paired study comparing Studio Soils students to a control group, my research does not constitute a true test of this model. In addition, there were conditions of this model that were likely not met by the current incarnation of Studio Soils (choice of learning tasks, explicit communication and explanation of expectations, and modeling and practice of high-level tasks). Suggestions for further improvements to the course that would help better meet the some of the other conditions and provide a better balance of support and challenge are described below.

Implications

Despite its narrow context, the research presented here (and in Chapter 3) provides support for the idea that studio-structured courses may enhance student learning and potentially contribute to their intellectual development. While not necessarily generalizable to other contexts, this study may provide insight useful to others who are interested in implementing a studio-style course.

The studio course described here in many ways provided a balance of challenge and support (one of Angelo's (1993) principles for improving higher learning) that could promote students' epistemological growth. The challenge students were faced with was primarily the very new experience of an integrated course that incorporated extensive cooperative active learning opportunities. Positive aspects of the course that provided support were the variety of learning and assessment methods used, being able to immediately apply their learning, and a primarily positive atmosphere that fostered a sense of community. However, there were several areas where the course could be improved to provide more support to some students and more challenge to others.

While the atmosphere of the studio course was generally perceived as positive, connected pattern students in particular will likely benefit from more support by better facilitating positive instructor-student interactions. As suggested by one student, and advocated by Billson and Tiberius (1991), incorporating ice-breaker activities into the first few classes and making sure the instructor(s) participate in these activities is one way to set a positive tone early on. Instructors could also attempt to learn (and use) students names as quickly as possible (Billson and Tiberius 1991, Angelo 1993) because most students (regardless of way or pattern of knowing) appreciated when they felt professors knew who they were. Assigning (and rotating) roles to students in the groups (i.e. spokesperson, notetaker, facilitator; Billson and Tiberius 1991, Soranno 2010) may also help facilitate instructor-student interactions during whole-class discussions because the spokesperson will already be prepared to speak. Additionally this may also help the quality of peer-to-peer interactions because it is more likely everyone's voice will be heard if a group member is specifically assigned the task of making sure that happens.

Because the structure of a studio course is already different from most students' prior experiences an additional form of support would be to organize the course so that the flow of lectures and activities remains relatively consistent on a day-to-day basis. This structure should be made clear to students on day one, and on days where the structure will differ from the norm students should know at least several days in advance what they will be doing differently. Such transparency and consistency would better align with the Felder and Brent (2004b) model (explicit communication and explanation of expectations) and would likely diminish some of the uncertainty felt by some students over what is expected of them. While this uncertainty was most keenly felt by a transitional knower expressing the interpersonal ('connected' type) pattern, many students across ways and patterns felt some amount of anxiety related to the newness of the course structure.

Support for students who place less value on interactions with peers (primarily separate pattern students) may be best enhanced by incorporating opportunities for individual work in addition to cooperating with peers. For example, students could work in class for two to five minutes writing an individual response to a discussion prompt before engaging in discussion with their peers. This may also help connected pattern students because they are the most likely to have their voices stifled during discussion; writing a response prior to engaging may help them to speak up. Ensuring that instructors are consistently interacting with students during cooperative activities (as opposed to waiting for students to ask questions) and wrapping up each cooperative activity with a mini-lecture or class discussion facilitated by the instructor (i.e. bringing class to appropriate closure from Billson and Tiberius 1991) may also help separate pattern students by providing a support to counter the challenge of working with peers.

Even though most of the students were absolute or transitional, there were students at independent and contextual knowing; because only three of the interviewed students fell into these ways of knowing, I have less data that would provide insight into improving the course structure for these students, but in general they would likely benefit from more challenge than support (particularly given the context of this course as a sophomore level introductory course); one suggestion from the Felder and Brent (2004b) model would be to implement more opportunities for students to make choices about what assignments they do. While this would be difficult to implement during class-time, students could be allowed to choose from among various types of homework assignments or choose from amongst a variety of problems or essay questions on homework or tests.

Limitations

The primary limitation of this study was the narrow context in which it took place: a single semester of Studio Soils in which all participants were from the Department of Natural Resources and the Environment at the University of New Hampshire. This will limit the extent to which my findings are transferable to others considering modifying to a studio structure. However, despite the narrow context, I was largely able to capture variability to the extent that the population varied (gender, year in school, GPA, final grade). This variability, and the complete description of the context (here and in Chapter 3), may aid others in determining the extent to which my findings may be applicable to similar course modifications.

Another limitation to this study was that I simultaneously played the roles of course designer, instructor, interviewer, and researcher. While this did grant me access to the environment, an insider perspective, and an opportunity to build rapport with the participants, the downside is that students may not have felt like they could be completely honest with me during their interviews. This was clearly not the case for some of the students who were quite verbose and did not hold back the negative comments (Owen) or constructive criticism (Philip), and other students used phrases such as "I'm not just saying this because you're here," (Celia, Ingrid) which suggests their responses were genuine. Nonetheless I cannot discount the possibility that the interviews did not truly capture the full range or extent of students' negative attitudes toward the class.

In order to maximize the number of student responses, the Measure of Epistemological Reflection was administered to students during class time. While this likely did increase the total number of participants, students may not have spent as much time or given as much thought to their responses as they would have if they had volunteered to participate outside of class. This was evident in a handful of responses that were not interpretable (not included in this research). For those students whose MER were interpretable, it is still possible that their actual written responses might not completely reflect their epistemological beliefs. However, I was able to use interviews as an additional source to help interpret 17 students' responses; in no case did their interviews lead me to change my interpretation of their MER, suggesting that their in-class responses on the MER were sufficient for identifying their way and pattern of knowing.

Conclusion

Students described four broad components of the studio structure that stood out the most to them: active learning, the integrated nature of the course, community, and variety. In particular, students attributed enhanced learning to the following subcategories: sharing, doing, thinking (active learning), learning then doing (integrated), variety of learning methods, and spacing/repetition. Comparing students' responses from the MER and initial interviews to their responses during the exit interview revealed some evidence that the studio structure may help promote epistemological growth. While there are areas where the course could still be improved (i.e. choice of assessments, better facilitation of instructor-student interactions, incorporating more opportunities for individual work and reflection), Studio Soils was largely successful at integrating active learning, spacing, and variety of learning methods into a studio-style learning environment.

Table 4.1. Demographics of students in the 2011 full cohort compared to the MER sample and the interview sample.

					By Year in School (%)			By Major (%)		
	N	Mean GPA	Mean Final Grade	Gender Ratio (F/M)	2nd	3rd	4th	ECS	Other NR	Non-NR
Full 2011population	70	3.03	85	0.94	14	46	39	56	31	13
MER sample	49	3.10	86	1.04	16	53	31	57	43	0
Interview sample	20	3.06	85	1.22	15	60	25	75	25	0

Notes: There were no statistical differences between the MER sample and 2011 population for GPA (t (46) = 0.97, P = 0.33), Final Grade (t (48) = 1.00, P = 0.32), Gender (X^2 (1) = 0.07, P = 0.85), or Year in School (X^2 (2) = 0.91, P = 0.63), or between the interview sample and the 2011 population for GPA (t (19) = 26, P = 0.80), Final Grade (t (19) = 0.05, P = 0.96), Gender (X^2 (1) = 0.26, P = 0.62), Year in School (X^2 (2) = 1.45, P = 0.50), or Major (X^2 (2) = 3.75, P = 0.15); there was a difference between the MER sample and the 2011 population for Major (X^2 (2) = 7.35, P = 0.02). ECS = Environmental Conservation Sustainability, Other NR = other Natural Resource majors, Non-NR = non-Natural Resource majors.

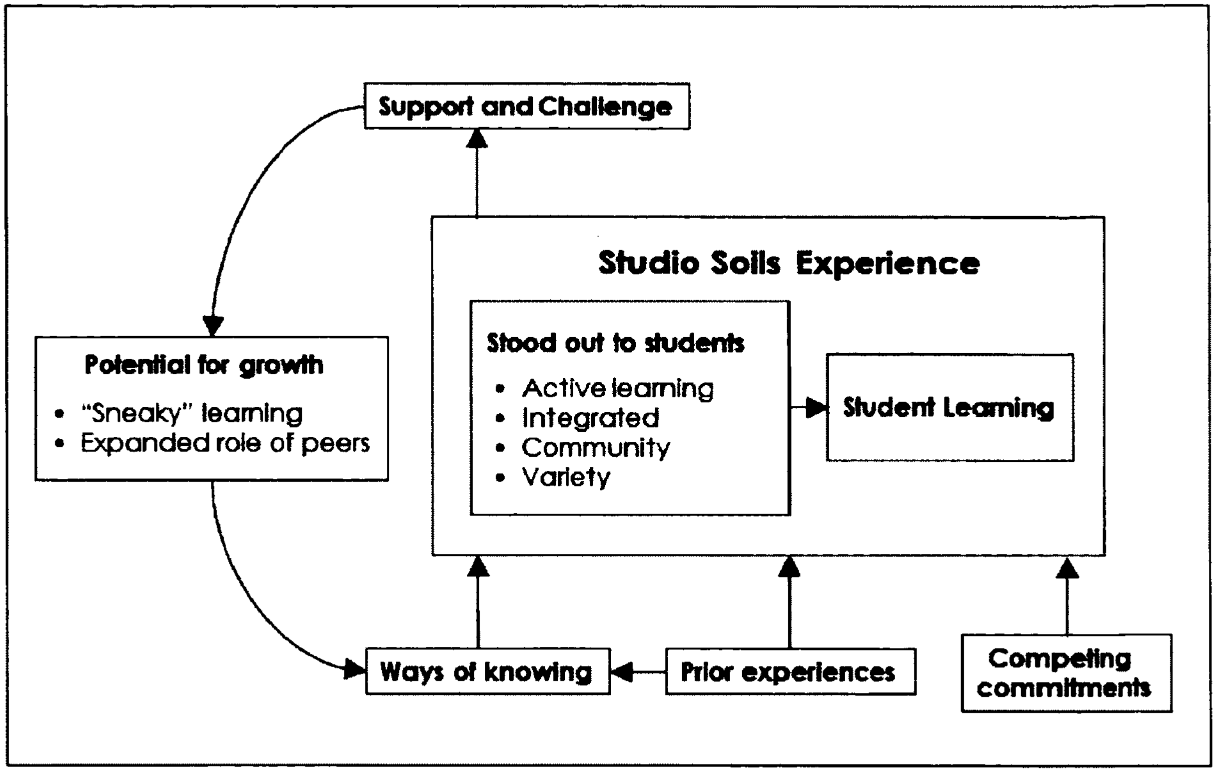
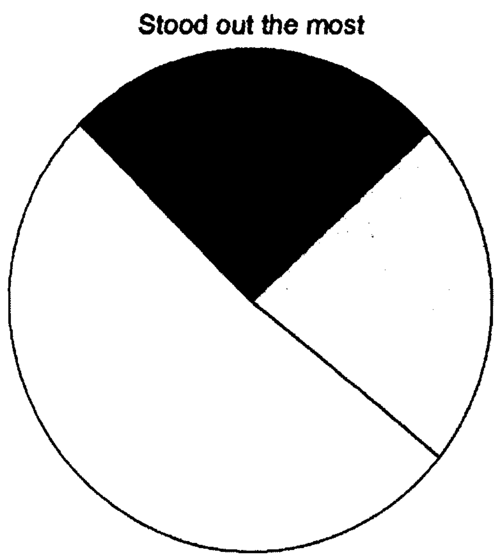


Figure 4.1. Conceptual model of the Studio Soils experience.



Stood out the most	# References (% of total)	# Students (% of total)
Active learning	**105 (52)**	**20 (100)**
Sharing	56 (28)	18 (90)
Doing	33 (16)	17 (85)
Thinking	16 (8)	8 (40)
Integrated	**46 (22)**	**15 (75)**
New experience	17 (8)	9 (45)
Learning then doing	16 (8)	11(55)
Better for schedule	13 (6)	9 (45)
[redacted]		
Meeting people	13 (6)	10 (50)
Approachability	11 (5)	8 (40)
Comfortable	11 (5)	4 (20)
Fun	3 (1)	3 (15)
[redacted]		
Learning methods	12 (6)	8 (40)
Assessment methods	2 (1)	2 (10)

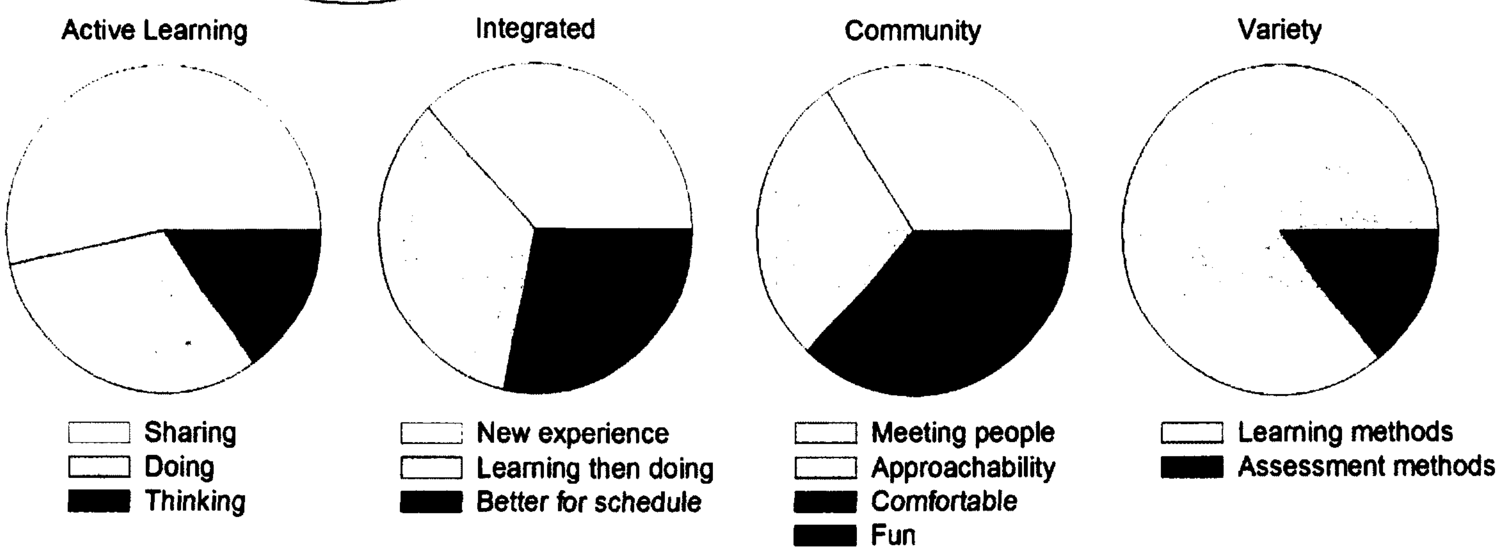
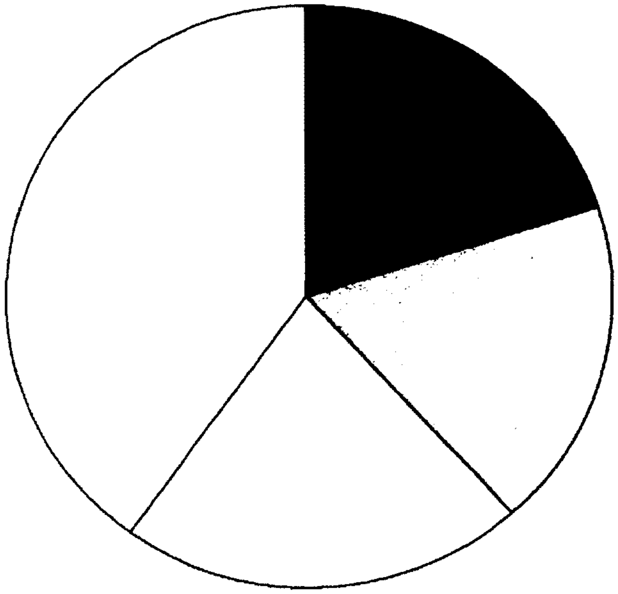
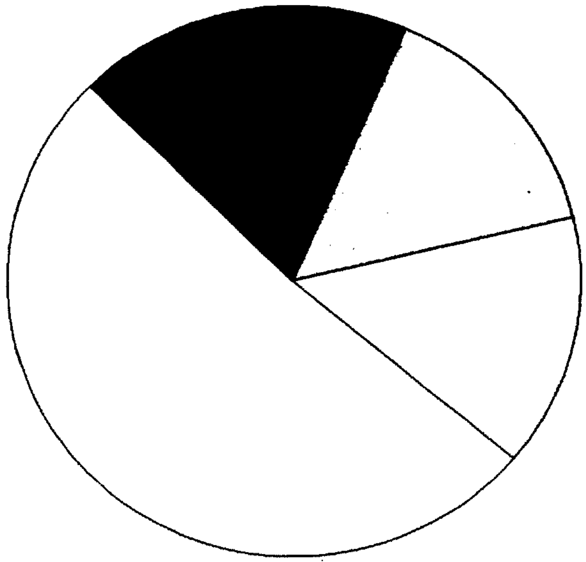


Figure 4.2. Main categories and subcategories that stood out to students the most in Studio Soils.



Helped students learn	# references (% of total)	# students (% of total)
Sharing	24 (40)	10 (50)
Thinking	13 (22)	6 (30)
Doing	11 (18)	5 (25)
[redacted]		

Figure 4.3. Aspects of Studio Soils that students identified as helping them learn.



Downsides	# References (% of total)	# Students (% of total)
Problems with peers	38 (51)	16 (80)
Time constraints	11 (15)	3 (15)
Not enough field time	**11 (15)**	**9 (45)**
[redacted]		

Figure 4.4. Downsides that stood out to students in Studio Soils.

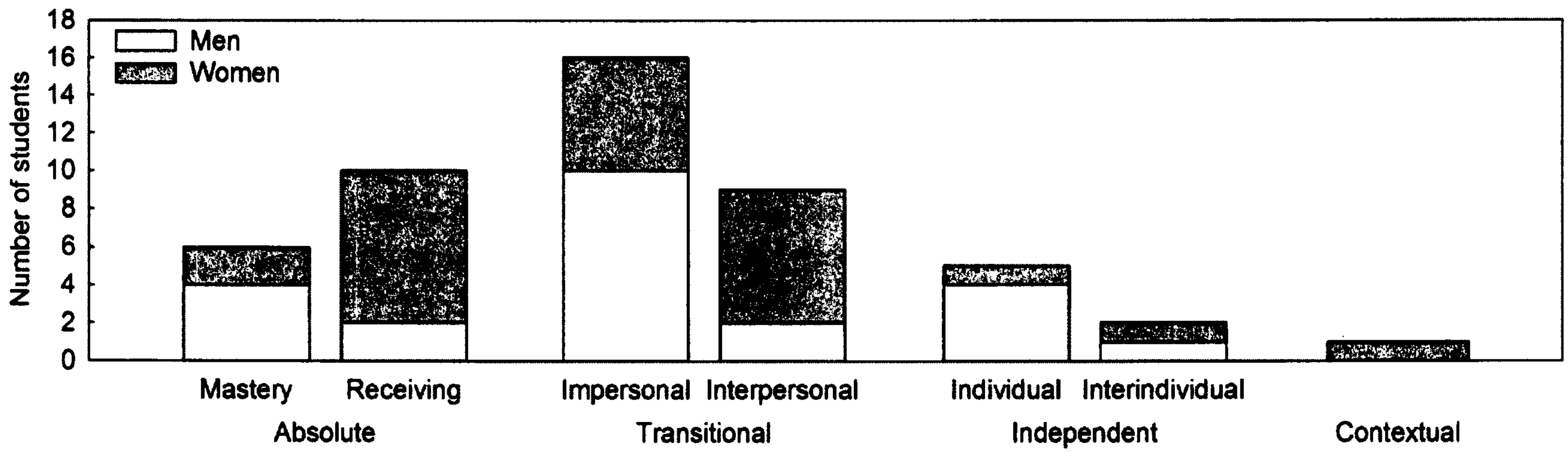


Figure 4.5. Number of students (by gender) expressing each pattern within a way of knowing.

CHAPTER 5

"SNEAKY LEARNING": MAKING A CASE FOR THE STUDIO LEARNING ENVIRONMENT

Despite a growing body of research showing that lecture is an ineffective mode of teaching (Freeman et al. 2014); lecture-based courses are the still the most prevalent mode of instruction in undergraduate science courses. Additionally, while most lecture-based science courses are accompanied by a separate lab section where students are able to apply their learning, these lab sessions are typically days (and in some cases weeks) ahead of or behind the lecture. Studio-style classes better integrate lecture and lab components by combining them into blocks of activity-based instruction; rather than three hours of lecture and two hours of lab per week, studio classes typically meet 2-3 times per week in 2-hour blocks.

From 2006 to 2008 I taught the lab sessions of a traditionally-taught (lecture-based with separate lab) introduction to soil science course at the University of New Hampshire, and from 2010 to 2012 I helped modify this course to the current studio-style structure where the lecture and lab sessions are combined and integrated with cooperative active learning (Studio Soils). This chapter presents four reasons for adopting the studio approach (derived from my research and personal experiences) and provides suggestions for those who may find the full studio-style of teaching and learning to be too daunting or impractical given a lack of infrastructure or support.

Reason 1: Removes the disconnect between lecture and lab

Having lab and lecture meeting at separate times can often be problematic as students often think of these as two very different entities and can have trouble making connections between the two. These feelings can be exacerbated when content covered in the lecture does not align well with that of lab. In extreme cases lecture can be weeks ahead of or behind lab, as explained by one of my students: "I had a class this semester where we would, you could say learn about it in lecture and then four days later have a lab about it but it never matched up correctly and then once you were done with the lab it was just over and you wouldn't talk about it again." By combining the lecture and the lab into a single unit, students are immediately able to apply their learning, as explained by a student:

> I think because they're together it makes it a lot easier to learn, because with the mini-lecture you learn about the topic real quick and then you do an activity about it. So it's not like I'm...cramming all this information in and then three days later going to a lab where I forgot what I learned at the beginning of the week... So I definitely think the studio way makes it easier to do that.

A bonus of the integrated nature is that students often appreciate the blocking into two 2-hour sessions per week because it is easier to fit into their schedule.

Reason 2: Caters to a diverse student population

A studio structure typically includes a variety of learning strategies (i.e., mini-lectures, hands-on lab and field exercises, data analysis, cooperative group activities) and assessment methods (i.e., homework, quizzes, writing assignments, tests). Students come to us with a variety of prior experiences, beliefs on the nature of knowledge, and beliefs on how they learn best. The inherent variety of a studio course can cater to students across these diverse backgrounds and can be especially beneficial for traditionally low performing students. For example, I found that low-performing students (based on their incoming GPA), scored higher on exams and research reports than students from the traditional course with equivalent GPAs. There was also a 14% decrease in students receiving < 70% for their final grade (Chapter 3). When different methods of teaching, learning, and assessment are combined, students get a variety of opportunities to not only apply their learning, but show the instructors, and themselves, what they have learned.

Reason 3: Fosters a sense of community

Students in traditional lecture-based courses, particularly if they are large-enrollment, often feel that their instructors are distant and unapproachable, and there are typically minimal opportunities to engage in meaningful ways with their peers. The studio structure increases peer-to-peer interactions and places the instructor with the students instead of as the "sage on stage." This can lead to a stronger sense of community and creates a positive learning environment. From a students' perspective this makes the instructor more approachable, allows them to meet more of their peers, and makes them more comfortable when sharing ideas and perspectives. From an instructor's perspective, interacting more frequently and directly with students can give us more insight into our students, as described by Alix Contosta (at the time, a teaching assistant for Studio Soils):

> As an instructor in the course it was a lot easier to keep track of where students were at any given moment...I just felt like I had a better idea of how students were doing, what they were understanding, what they weren't, what their challenges were, and especially the students who were really struggling.

Reason 4: Has the potential to promote intellectual growth

Lecturing involves passive teaching (if not passive learning) and emphasizes the instructor as an authority figure who is the only valid source of knowledge, while students are relegated to the role of empty vessel, whose sole job it is to absorb and memorize what instructors are telling them. In contrast, the studio structure places more responsibility with the learner and increases peer-to-peer interactions where students' could help each other understand the material, share ideas, and think about things in different ways. It also places the instructor with the students instead of as the "sage on stage." These features can decrease students' dependence on instructors and increase their reliance on themselves and their peers, which has the potential to promote epistemological growth in students (more complex views on the nature of knowledge and knowing). One mechanism for this is "sneaky learning" where students who have been trained by lecture-based courses to believe that the way people learn is by receiving information directly from the mouths of authority figures suddenly realize they're learning even though they're not being lectured at: "When it got time for the first exam I didn't realize that I had really learned so much by continuously "Doing" instead of sitting and listening to lecture for 4 hours a week."

Alternatives to Studio

While the advantages of the studio structure are many (see also Chapter 4), it is not without its faults, most of which are related to planning and implementation. It requires extensive initial effort to re-design a course, to reduce/rethink lectures, and design cooperative learning activities. It requires support (administrative, financial, teaching assistants, etc.) and infrastructure. In addition to the initial effort to get the course up and running, it also requires more effort, particularly in the first few years, to figure out timing, what works, and what doesn't work. Expect some chaos in the first semester, particularly in the first half of the first semester. Some students also reported that it required more effort, in some cases explaining that they just "weren't in the mood" to put in the energy. The newness of the structure can also be confusing to students and may cause some anxiety due to uncertainty over what is expected of them (though this can be minimized by clearly explaining the structure of the course at the beginning of the semester and by being largely consistent day-to-day with the course organization).

If a studio structure is not for you, consider starting small by implementing alternative strategies. Field et al. (2011) outline eleven excellent soil science teaching principles, most of which are broadly applicable to other disciplines. You may also consider one or more of the following as a means of incorporating some of the benefits of the studio structure into your lecture-based courses.

Align the labs as closely as possible to the lectures. In lecture, make connections to what students are doing in labs; in labs make connections to what students are hearing in lectures (spend 5-10 minutes reviewing what was covered in lecture); many students experience frustration when their labs meet several days after the associated lecture or when the lecture and labs aren't aligned at all.

Incorporate short activities into lectures. To the extent that it is feasible (given class size, infrastructure), incorporate breaks into lectures (every 15-20 min if possible) and do an activity that allows students to reflect on their understanding, apply their learning, and/or make connections to what they already know. For example, you could use Minute Papers or other types of formative assessments (Angelo and Cross 1993) to give students the opportunity to reflect on their learning and give you the opportunity to see whether students are learning what you think they're learning.

Attend labs. If the labs are taught by someone besides you, consider making regular appearances in the labs. Perhaps participate with students in the activities directed by the TA and rotate amongst groups. Students appreciate the additional interaction and it allows you to talk with your students rather than at them.

Convey your enthusiasm for the discipline. Use your lecture time to convey your experiences and make connections to the world around us. Enthusiasm can go a long way towards engaging students, even in a lecture-based course. When we tell stories about our experiences and make connections to students' lives, their community, other classes/disciplines, global environmental concerns etc., students' sit up, pay attention, get excited, and remember.

Conclusion

If you have the appropriate infrastructure and support, the studio-style course has a lot going for it. In my opinion the extra effort involved throughout the process is more than balanced by the benefits of the modification. The course has been largely well-received by students and we have shown improvements in performance and shifts in viewpoints on how learning happens. If for no other reason, students' realizations that they aren't just passive receivers of knowledge via the "sneaky learning" phenomenon is an excellent reason to consider the studio structure. However, the studio structure may not be feasible in many situations due to lack of infrastructure or support. Still, there are alternative strategies that may provide some of the same benefits: 1) making stronger connections between lectures and labs, 2) making regular appearances in labs, 3) incorporating active-learning strategies into lectures, and 4) conveying your passion for the discipline.

CONCLUSION TO PART II

In Part II of this dissertation I described research I undertook to better understand how structure influences function in the context of an undergraduate introductory soil science course. In Chapter 3 I asked whether course structure (traditional versus studio) influenced the function (student performance) of the course. In Chapter 4 I looked at student perspectives on their learning and experiences (function) in the studio structure and asked whether students' ways of knowing (internal structure) influenced this function.

I found that students in the studio course outperformed students in the traditional course; there was also a 14% drop in students' receiving < 70% for their final grade. Low-performing students (based on their incoming GPAs) benefitted the most from the studio structure, scoring an average of 10 points higher on research reports and exams than students from the traditional course with equivalent GPAs. Students described four aspects of Studio Soils that stood out to them: active learning, the integrated nature of the course, community, and variety of learning and assessment methods. While students did not relate all of these aspects to their learning, they did specifically link doing, thinking, sharing (active learning), learning then doing (integrated), the variety of learning methods, and spacing/repetition with improved learning. In some ways, students' ways of knowing informed their experiences in the course. I also found some evidence to support the idea that the studio structure may help promote epistemological growth via "sneaky learning" and an expanded role of peers.

Together this research shows that structure (studio versus traditional courses) has a measurable and positive effect on function (students' performance, perspectives on their experiences and their learning, and potentially their intellectual growth) in the context of an undergraduate introductory soil science course.

LITERATURE CITED IN PART II

Amador, J.A., and J.H. Görres. 2004. A problem-based learning approach to teaching introductory soil science. Journal of Natural Resources & Life Sciences Education 33: 21-27.

Angelo, T.A. 1993. A "teacher's dozen:" Fourteen general, research-based principles for improving higher learning in our classrooms. *AAHE Bulletin* April: 3-13.

Angelo, T.A., and K.P. Cross 1993. *Classroom Assessment Techniques*, 2nd edition. San Francisco, CA: Jossey-Bass.

Andrews, T.M., M.J. Leonard, C.A. Colgrove, and S.T. Kalinowski. 2011. Active learning *not* associated with student learning in a random sample of college biology courses. *CBE – Life Sciences Education* 10: 394-405.

Armbruster, P., M. Patel, E. Johnson, and M. Weiss. Active learning and student-centered pedagogy improve student attitudes and performance in introductory biology. *CBE-Life Sciences Education* 8: 203-213.

Baxter Magolda, M.B. 1992. *Knowing and reasoning in college: Gender-related patterns in students' intellectual development*. San Francisco, CA: Jossey-Bass.

Baxter Magolda, M.B. 2001. A constructivist revision of the Measure of Epistemological Reflection. *Journal of College Student Development* 42(6): 520-534

Beichner, R.J., J.M. Saul, D.S. Abbott, J.J. Morse, D.L. Deardorff, R.J. Allain, S.W. Bonham, M.H. Dancy, and J.S. Risley. 2007. The student-centered activities for large enrollment undergraduate programs (SCALE-UP) project. In: *Research-Based Reform of University Physics*, Eds. E.F. Redish and P.J. Cooney. Reviews in PER Vol. 1. College Park, MD: American Association of Physics Teachers.

Belenky, M.F., B.M. Clinchy, N.R. Goldberger, and J.M. Tarule. 1986. *Women's ways of knowing: The development of self, voice, and mind*. New York, NY: BasicBooks.

Billson J.M. and R.G. Tiberius. 1991. Effective social arrangements for teaching and learning. *New Directions for Teaching and Learning* 45: 87-110.

Bonaham, S.W., D.L. Deardorff, and R.J. Beichner. 2003. Comparison of student performance using web and paper-based homework in college-level physics. *Journal of Research in Science Teaching* 40(10): 1050-1071.

Bonwell, C.C. and J.A. Eison. 1991. Active learning: Creating excitement in the classroom. *ASHE-ERIC Higher Education Report No. 1*. Washington, D.C.: The George Washington University, School of Education and Human Development.

Brewe, E., V. Sawtelle, L.H. Kramer, G.E. O'Brien, I. Rodriguez, and P. Pamela. 2010. Toward equity through participation in Modeling Instruction in introductory university physics. *Physical Review Special Topics – Physics Education Research* 6: 010106.

Brookshire, R.G., and S.W. Palocsay. 2005. Factors contributing to the success of undergraduate business students in management science courses. *Decision Sciences Journal of Innovative Education* 3(1): 99-108.

Bull, N.H. and J.C. Clausen. 2000. Structured group learning in undergraduate and graduate courses. *Journal of Natural Resources & Life Sciences Education* 29: 46-50.

Creech, L.R., and R.D. Sweeder. 2012. Analysis of student performance in large-enrollment life science courses. *CBE – Life Sciences Education* 11: 386-391.

Crotty, M. 1998. *The foundations of social research: Meaning and perspective in the research process*. Thousand Oaks, CA: Sage.

Crouch, C.H., and E. Mazur. 2001. Peer instruction: Ten years of experience and results. *American Journal of Physics* 69(9): 970-977.

Dauer, J.T., J.L. Momsen, E.B. Speth, S.C. Makohon-Moore, and T.M. Long. 2013. Analyzing change in students' gene-to-evolution models in college-level introductory biology. *Journal of Research in Science Teaching* 50(6): 639-659.

DeCuir-Gunby, J.T., P.L. Marshall, and A.W. McCulloch. 2011. Developing and using a codebook for the analysis of interview data: An example from a professional development research project. *Field methods* 23: 136-155.

Deslauriers, L., and C. Wieman. 2011. Learning and retention of quantum concepts with different teaching methods. *Physical Review Special Topics – Physics Education Research* 7: 010101.

Dianovsky, M.T., and D.J. Wink. 2012. Student learning through journal writing in a general education chemistry course for pre-elementary education majors. *Science Education* 96: 543-565.

Dori, Y.J. and J. Belcher. 2005. How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *The Journal of the Learning Sciences* 14(2): 243-279.

Easter, D.C. 2010. Factors influencing student prerequisite preparation for and subsequent performance in college Chemistry Two: A statistical investigation. *Chemical Education Research* 87(5): 535-540.

Ebert-May, D., C. Brewer, and S. Allred. 1997. Innovation in large lectures – teaching for active learning. *Bioscience* 47(9): 601-607.

El-Farargy, N. 2009. Chemistry for student nurses: Applications-based learning. *Chemistry Education Research and Practice* 10: 250-260.

El-Farargy, N. 2010. Evaluation of a chemistry curriculum intervention using the Perry model of intellectual development. *Chemistry Education Research and Practice* 11: 98-106.

Efthimiou, C., D. Maronde, T. McGreevy, E. del Barco, and S. McCole. 2011. Implementing elements of The Physics Suite at a large metropolitan research university. *Physics Education* 46(4): 421-429.

Felder, R.M., and R. Brent. 2004b. The intellectual development of science and engineering students. Part 2: Teaching to promote growth. *Journal of Engineering Education* 93(4): 279-291.

Field, D.J., A.J. Koppi, L.E. Jarrett, L.K. Abbot, S.R. Cattle, C.D. Grant, A.B. McBratney, N.W. Menzies, A.J. Weatherley. 2011. Soil Science teaching principles. Geoderma 167-168: 9-14.

Freeman, S., S.L. Eddy, M. McDonough, M.K. Smith, N. Okoroafor, H. Jordt, and M.P. Wenderoth. 2014. Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences* 111(23): 8410-8415.

Freeman, S., D. Haak, and M.P. Wenderoth. 2011. Increased course structure improves performance in introductory biology. *CBE – Life Sciences Education* 10: 175-186.

Freeman, S., E. O'Connor, J.W. Parks, M. Cunningham, D. Hurley, D. Haak, C. Dirks, and M.P. Wenderoth. 2007. Prescribed active learning increases performance in introductory biology. *CBE-Life Sciences Education* 6: 132-139.

Gatch, D. 2010. Restructuring introductory physics by adapting an active learning studio model. *International Journal for the Scholarship of Teaching and Learning* 4(2): Art. 14.

González-Sancho, J.M., A. Sánchez-Pacheco, M. Lasa, S. Molina, F. Vara, and L. del Peso. 2013. The use of an active learning approach to teach metabolism to students of nutrition and dietetics. *Biochemistry and Molecular Biology Education* 41(3): 131-138.

Gottfried, A.C., R.D. Sweeder, J.M. Bartolin, J.A. Hessler, B.P. Reynolds, I.C. Stewart, B.P. Coppola, and M.M. Banaszak Holl. 2007. Design and implementation of a studio-based general chemistry course. *Journal of Chemical Education* 84: 265-270.

Grove, N.P., and S. Lowery Bretz. 2010. Perry's Scheme of Intellectual and Epistemological Development as a framework for describing student difficulties in learning organic chemistry. *Chemistry Education Research and Practice* 11: 207-211.

Haak, D.C., J. HilleRisLambers, E. Pitre, and S. Freeman. 2011. Increased structure and active learning reduce the achievement gap in introductory biology. *Science* 332: 1213-1216.

Hake, R.R. 1998. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics* 66(1): 64-74.

Handelsman, J., D. Ebert-May, R. Beichner, P. Bruns, A. Chang, R. DeHaan, J. Gentile, S. Lauffer, J. Stewart, S.M. Tilghman, and W.B. Wood. 2004. Scientific teaching. *Science* 304: 521-522.

Henrie, R.L., R.H. Aron, B.D. Nelson, and D.A. Poole. 1997. Gender-related knowledge variations within geography. *Sex Roles* 36(9/10): 605-623.

Higham, J., and P.J. Steer. 2004. Gender gap in undergraduate experience and performance in obstetrics and gynaecology: Analysis of clinical experience logs. *British Medical Journal* 328(7432): 142-143.

Hofer, B.K. 2004. Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology* 29: 129-163.

Hofer, B.K., and P.R. Pintrich. 1997. The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research* 67(1): 88-140.

Hsieh, C.T. 2012. Factors related to students's learning of biomechanical concepts. *Journal of College Science Teaching* 41(4): 82-89.

Huang, S., and N. Fang. 2013. Predicting student academic performance in an engineering dynamics course: A comparison of four types of predictive mathematical models. *Computers & Education* 61: 133-145.

Jensen, J.L., and A. Lawson. 2011. Effects of collaborative group composition and inquiry instruction on reasoning gains and achievement in undergraduate biology. *CBE – Life Sciences Education* 10: 64-73.

Katung, M., A.H. Johnstone, and J.R. Downie. 1999. Monitoring attitude changes in students to teaching and learning in a university setting: A study using Perry's developmental model. *Teaching in Higher Education* 4(1): 43-60.

King, P.M., and Kitchener, K.S. 1994. *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults.* San Francisco, CA: Jossey-Bass.

Kornell, N. and R.A. Bjork, R.A. 2008. Learning concepts and categories: Is spacing the "enemy of induction"? *Psychological Science* 19(6): 585-592.

Kost, L.E., S.J. Pollock, and N.D. Finkelstein. 2009. Characterizing the gender gap in introductory physics. *Physical Review Special Topics – Physics Education Research* 5: 010101.

Kost-Smith, L.E., S.J. Pollock, and N.D. Finkelstein. 2010. Gender disparities in second-semester college physics: The incremental effects of a "smog of bias." *Physical Review Special Topics – Physics Education Research* 6: 020112.

Kovac, J. 1999. Student active learning methods in general chemistry. *Journal of Chemical Education* 76: 120-124.

Lauer, S., J. Momsen, E. Offerdahl, M. Kryjevskaia, W. Christensen, and L. Montplaisir. 2013. Stereotyped: Investigating gender in introductory science courses. *CBE – Life Sciences Education* 12: 30-38.

Lewis, S.E. 2011. Retention and reform: An evaluation of Peer-Led Team Learning. *Journal of Chemical Education* 88: 703-707.

Lian, J. and F. He. 2013. Improved performance of students instructed in a hybrid PBL format. *Biochemistry and Molecular Biology Education* 41(1): 5-10.

Lo, C. and A.N. Monge. 2013. Inclusive, interactive classroom as student-learning facilitator. *International Journal for the Scholarship of Teaching and Learning* 7(2): Article 13. Available at: http://digitalcommons.georgiasouthern.edu/ij-sotl/vol7/iss2/13/

Lorenzo, M., C.H. Crouch, and E. Mazur. 2006. Reducing the gender gap in the physics classroom. *American Journal of Physics* 74(2): 118-122.

Madsen, A., S.B. McKagan, and E.C. Sayre. 2013. Gender gap on conceptual inventories in physics: What is consistent, what is inconsistent, and what factors influence the gap? *Physical Review Special Topics – Physics Education Research* 9: 020121.

Marra, R.M., B. Palmer, and T.A. Litzinger. 2000. The effects of a first-year engineering design course on student intellectual development as measured by the Perry scheme. *Journal of Engineering Education* 89(1): 39-45.

Marx, D.M., and J.S. Roman. 2002. Female role models: Protecting women's math test performance. *Personality and Social Psychology Bulletin* 28: 1183-1193.

Mayer, R.E. 2011. *Applying the Science of Learning*. New York, NY: Pearson.

Mazur, E. 2009. Farewell, lecture? *Science* 323: 50-51.

Mazzarone, K.M. and N.P. Grove. 2013. Understanding epistemological development in first- and second-year chemistry students. *Journal of Chemical Education* 90: 968-975.

Meltzer, D.E. and K. Manivannan. 2002. Transforming the lecture-hall environment: The fully interactive physics lecture. *American Journal of Physics* 70(60): 639-654.

Merriam, S.B. 2009. *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey Bass.

Meyers, C. and T.B. Jones. 1993. *Promoting active learning: Strategies for the college classroom*. San Francisco, CA: Jossey Bass.

Michel, N., J.J. Cater III, and O. Varela. 2009. Active versus passive teaching styles: An empirical study of student learning outcomes. *Human Resource Development Quarterly* 20 (4): 397-418.

Miyake, A., L.E. Kost-Smith, N.D. Finkelstein, S.J. Pollock, G.L. Cohen, and T.A. Ito. 2010. Reducing the gender achievement gap in college science: A classroom study of values affirmation. *Science* 330: 1234-1237.

Montelone, B.A., D.A. Rintoul, and L.G. Williams. 2008. Assessment of the effectiveness of the studio format in introductory undergraduate biology. *CBE-Life Sciences Education* 7: 234-242.

Nogaj, L.A. 2013. Using active learning in a studio classroom to teach molecular biology. *Journal of College Science Teaching* 42(6): 50-55.

Oliver-Hoyo, M.T. and Allen, D. 2005. Attitudinal effects of a student-centered active learning environment. *Journal of Chemical Education* 82: 944-949.

Oliver-Hoyo, M.T., D. Allen, W.P. Hunt, J. Hutson, and A. Pitts. 2004. Effects of an active learning environment: Teaching innovations at a Research I institution. *Journal of Chemical Education* 81: 441-448.

Paschler, H., P. Bain, B. Bottge, A. Graesser, K. Koedinger, M. McDaniel, and J. Metcalfe. 2007. *Organizing Instruction and Study to Improve Student Learning* (NCER 2007-2004). Washington, DC: National Center for Education Research, Institute of Education Sciences, U.S. Department of Education.

Pavelich, M.J., and W.S. Moore. 1996. Measuring the effect of experiential education using the Perry model. *Journal of Engineering Education* 85(4): 287-292.

Pearsall, N.R., J.J. Skipper, and J.J. Mintzes. 1997. Knowledge restructuring in the life sciences: A longitudinal study of conceptual change in biology. *Science Education* 81: 193-215.

Perry, W.G. 1970. *Forms of intellectual and ethical development in the college years: A scheme*. Troy, MO: Hold, Rinehart, & Winston.

Pollock, S.J., N.D. Finkelstein, and L.E. Kost. 2007. Reducing the gender gap in the physics classroom: How sufficient is interactive engagement? *Physics Review Special Topics – Physics Education Research* 3: 010107.

Preszler, R.W. 2009. Replacing lecture with peer-led workshops improves student learning. *CBE – Life Sciences Education* 8: 182-192.

Rauschenberger, M.M., and R.D. Sweeder. 2010. Gender performance differences in biochemistry. *Biochemistry and Molecular Biology Education* 38(6): 380-384.

Schommer, M. 1990. Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology* 82(3): 498-504.

Schommer, M., A. Crouse, and N. Rhodes. 1992. Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology* 84(4): 453-443.

Severiens, S., and G. Ten Dam. 1998. Gender and learning: comparing two theories. *Higher Education* 35(3): 329-350.

Soranno, P.A. 2010. Improving student discussions in graduate and undergraduate courses: Transforming the discussion leader. *Journal of Natural Resources & Life Sciences Education* 39: 84-91.

Tolhurst, D. 2007. The influence of learning environments on students' epistemological beliefs and learning outcomes. *Teaching in Higher Education* 12(2): 219-233.

Thompson, J., S. Jungst, J. Colletti, B. Licklider, and J. Benna. 2003. Experiences in developing a learning-centered natural resources curriculum. *Journal of Natural Resources & Life Sciences Education* 32: 23-31.

Udovic, D., D. Morris, A. Dickman, J. Postlethwait, and P. Wetherwax. 2002. Workshop Biology: Demonstrating the effectiveness of active learning in an introductory biology course. *Bioscience* 52(3): 272-281.

Ueckert, C., A. Adams, and J. Lock. 2011. Redesigning a large-enrollment introductory biology course. *CBE – Life Sciences Education* 10: 164-174.

Walker, J.D., S.H. Cotne, P.M. Baepler, and M.D. Decker. 2008. A Delicate balance: Integrating active learning into a large lecture course. *CBE-Life Sciences Education* 7: 361-367.

Whitmire, E. 2004. The relationship between undergraduates' epistemological beliefs, reflective judgment, and their information-seeking behavior. *Information Processing and Management* 40: 97-111.

Willoughby, S.D., and A. Metz. 2009. Exploring gender differences with different gain calculations in astronomy and biology. *American Journal of Physics* 77: 651-657.

Wright, J.C., S.B. Millar, S.A. Kosciuk, D.L. Penberthy, P.H. Williams, and B.E. Wampold. 1998. A novel strategy for assessing the effects of curriculum reform on student competence. *Journal of Chemical Education* 75(8): 986-992.

Wright, R., S. Cotner, and A. Winkel. 2009. Minimal impact of organic chemistry prerequisite on student performance in introductory biochemistry. *CBE – Life Sciences Education* 8: 44-54.

Yadav, A., D. Subedi, M.A. Lundeberg, and C.F. Bunting. 2011. Problem-based learning: Influence on students' learning in an electrical engineering course. *Journal of Engineering Education* 100(2): 253-280.

Zorn, C.R., D.A. Ponick, and S.D. Peck. 1995. An analysis of the impact of participation in an international study program on the cognitive development of senior baccalaureate nursing students. *Journal of Nursing Education* 34(2): 67-70.

APPENDICES FOR PART II

APPENDIX 3: EXAMPLE ACTIVITIES AND ADDITIONAL QUANTITATIVE ANALYSES

Example Activities and Discussion Prompts

Factors Influencing Soil Formation: Parent Material

Group member names____
Group #__________

Parent material is the geological stuff from which soil originates. Its hardness, porosity, and mineralogy all influence the type of soil that develops. There are two different types of parent material: residual, or "in place" parent materials, and transported parent materials. At your table you have maps depicting the bedrock geology of Massachusetts (Map 1), the different types of surficial deposits that overlie that bedrock (Map 2), and the soil series for one area of the state (Map 3). Using what you've learned so far about soil formation, answer the following questions (you may use your textbook; see pp 26-43):

1. What types of deposits are depicted in Map 2?

2. What was the source of these deposits?

3. What do you think was more important in determining the current soils of Massachusetts—the bedrock geology or surficial deposits? Why? Hint: compare the AOI in Maps 1 & 2 with Map 3.

4. Based on what you know about soil texture and the parent materials shown below, what's your best guess for the textural classes for the soils shown in Map 3? Explain why you chose that textural class.

Soil Texture Activity

Group Member Names ____

Group # ________

Part 1. Practicing Texture by Feel
Spend a few minutes practicing the texture by feel method on each of the soils provided. Record the textural class for each soil below (note that for the VA and TX soils the kneading step may take a couple of minutes).

VA Ultisol: ____

TX Vertisol: ____

NH Inceptisol: ____

Part 2. Using the Texture Triangle to convert texture class to % sand, silt, and clay.

For each of the soils above, refer to the textural triangle to determine the range in % sand, % silt, and % clay from the textural classes (e.g. 0-20% sand, 80-100% silt, 0-10% clay)

VA Ultisol: ____

TX Vertisol: ____

NH Inceptisol: ____

Part 3. Using the Texture Triangle: converting % sand, silt, and clay to a texture class

Use the texture triangle to determine the texture class for the three examples below

1) 50% sand, 20% silt, 30% clay: ______________________________

2) 15% sand, 50% silt, 35% clay: ______________________________

3) 40% sand, 40% silt, 20% clay: ______________________________

Part 4. Relating Texture to Soil Properties

Discuss the following questions with your group and then write a short response in the space provided (Refer to your textbook or other sources if necessary).

Of the VA Ultisol, TX Vertisol, NH Inceptisol:

1) Which soil do you think is likely to have the best permeability? Explain your reasoning.

2) Which soil do you think would be best for growing plants from a texture perspective? Explain your reasoning.

3) We'll cover Vertisols next week, but one characteristic of these soils is that they have high content of expansive clays that shrink when dry and swell when wet. During dry seasons the shrinking can cause deep cracks to form. Based on this information and the soil texture you determined, which soil would you expect to have the most problems with compaction? Explain your reasoning.

Short Writing Prompt

- What are some things you've learned in this class that you didn't already know (describe)?
- How do you understand the process of soil formation?
- How well do you understand the soil classification system?
- How do you understand the relationship of soils to the lithosphere?
- Do you think that your understanding of these topics (or others) has improved?
- End with a question or two that you are left with in relation to the topics we've covered so far.

Potential Covariables Not Discussed in Chapter 3

Only grade point average (GPA) was reported as a covariable in Chapter 3; however, I gathered data on several other potential covariables including students' age, whether they had taken chemistry, and their socioeconomic status (SES). Students' age and SES were gathered as part of the demographic questionnaire (Appendix 6); students also reported on an in-class survey whether or not they had taken chemistry. Because some students gave me permission to access their records I also tried calculating additional metrics: number of lab classes taken, whether they had taken physics, math, or statistics, their GPA for chemistry classes only, their GPA for physics, math, and statistics classes only, their GPA for lab classes only, and their GPA for biological science and natural resource classes only. However, because only 70 students gave me permission to access their records and most of the students were from the second studio year, I didn't have enough students to perform an analysis of covariance (not enough replication once you split by course type, gender, and year in school). Only 75 students fully completed the SES portion of the questionnaire and a preliminary analysis using SES as a covariable (I used the factor scores from the first component of a principle components analysis to create an SES variable) showed no influence of SES on student performance except some higher order interactions that were not meaningful (data not shown).

Thus, in addition to GPA, I only performed complete analyses of covariance using students' age and their chemistry background. For students' age, I originally ran the analysis using students' actual ages; however, even though there were some statistical differences, it was clear from the data that the only differences were between younger and older students. Therefore I created a binary variable (traditional age (19-22) or non-traditional age (23-34) instead. Chemistry background was also a binary variable (taken or not taken).

Age and chemistry background were first used as dependent variables to see if they were influenced by the treatment effects (course structure, gender, and year in school; Proc Glimmix (binary distribution specified), SAS 9.3; Appendix Table A3.1). There was a significant influence of students' year in school on the proportion of students' who had taken chemistry with the proportion increasing as students' year in school increased (Appendix Figure A3.1 C). There was also a trend for a decreasing proportion of traditional age students with increasing year in school, but it was not significant (Appendix Figure A3.1 F). Neither the proportion of students who had taken chemistry nor the proportion of students who were traditional age varied significantly between course structures or between male and female students (Appendix Figure A3.1 A-B and D-E).

I next performed analysis of covariance using linear mixed effects models where course type and gender were used as fixed effects, age or chemistry background were covariables, and section (within year) was specified as random. There was no effect of chemistry background on students' quiz performance or their final grade, but for reports there was a significant interaction between course structure and chemistry background and for exams there was a significant interaction between gender and chemistry background (Appendix Table A3.2). For reports, there was no difference due to chemistry experience in the studio course but in the traditional course students who had taken chemistry had lower grades than those who had not taken chemistry (Appendix Figure A3.2 B). For exams, female students did equally well regardless of prior chemistry experience but male students who had prior chemistry experience did better than male students who had not taken chemistry (Appendix Figure A3.2 D).

Students' report grades and final grades in the course did not vary significantly with students' age, but for quizzes there was a significant interaction between course structure and students' age and for exams there was a significant interaction between gender and students age (Appendix Table A3.2). For quizzes, older students did better than younger students in the traditional course but there was no difference due to age in the studio course and there was no difference between traditional and studio within younger students or within older students (Appendix Figure A3.3 A). For exams, older male students performed significantly lower than younger male students and significantly lower than older female students, but there was no difference between male and female students within younger students (Appendix Figure A3.3 C).

Table A3.1. Linear mixed effect model F values (num df, den df) for models testing the influence of treatment effects (course structure, gender, year in school) on potential covariables; no interactions were significant.

Effect	GC	Age
Course Structure	0.00 (1, 5) ns	0.70 (1, 6) ns
Gender	0.43 (1, 170) ns	0.05 (1, 90) ns
Year in School	7.14 (2, 170)***	2.11 (2, 90) ns

Note: GC = prior general chemistry experience, ns = not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table A3.2. Linear mixed effects model F values (num df, den df) for main effects (course structure and gender), potential covariables (GC and Age), and significant interactions from analysis of covariance models using assessment types (Quiz, Report, Exam, Final) as dependent variables..

Effect	Quiz	Report	Exam	Final
Course Structure	0.51 (1, 6) ns	6.42 (1, 7)*	13.05 (1, 10)**	3.05 (1, 6) ns
Gender	6.53 (1, 169)**	5.83 (1, 168)*	23.25 (1, 164)***	18.26 (1, 171)***
Course Structure*Gender			13.27 (1, 164)***	5.01 (1, 171)*
GC	0.35 (1, 171) ns	1.94 (1, 171) ns	0.93 (1, 164) ns	0.15 (1, 171) ns
GC*Course Structure		4.16 (1, 171)*		
GC*Gender			6.93 (1, 164)**	
Course Structure	0.87 (1, 4) ns	9.01 (1, 10)**	0.58 (1, 10) ns	1.40 (1, 10) ns
Gender	0.02 (1, 88) ns	6.72 (1, 85)**	7.82 (1, 84)**	6.50 (1, 85)**
Course Structure*Gender	3.86 (1, 88)*			
Age	4.03 (1, 85)*	2.28 (1, 85) ns	0.00 (1, 84) ns	0.64 (1, 85) ns
Age*Course Structure	3.83 (1, 85)*			
Age*Gender			4.03 (1, 84)*	

Notes: GC = prior general chemistry experience; ns = not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

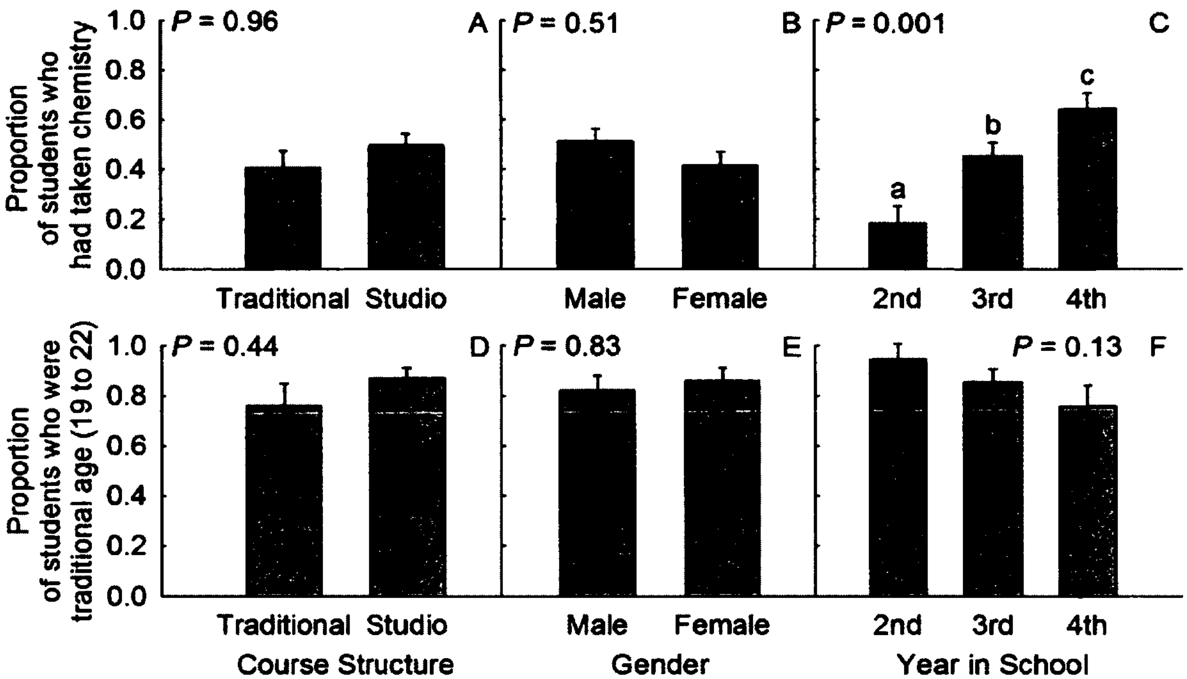


Figure A3.1. The influence of fixed treatment effects (course structure (left), students' gender (middle), and students' year in school (right)) on prior chemistry experience (A-C) and students' age (D-F). N = 176 for A-C; N = 95 for D-F.

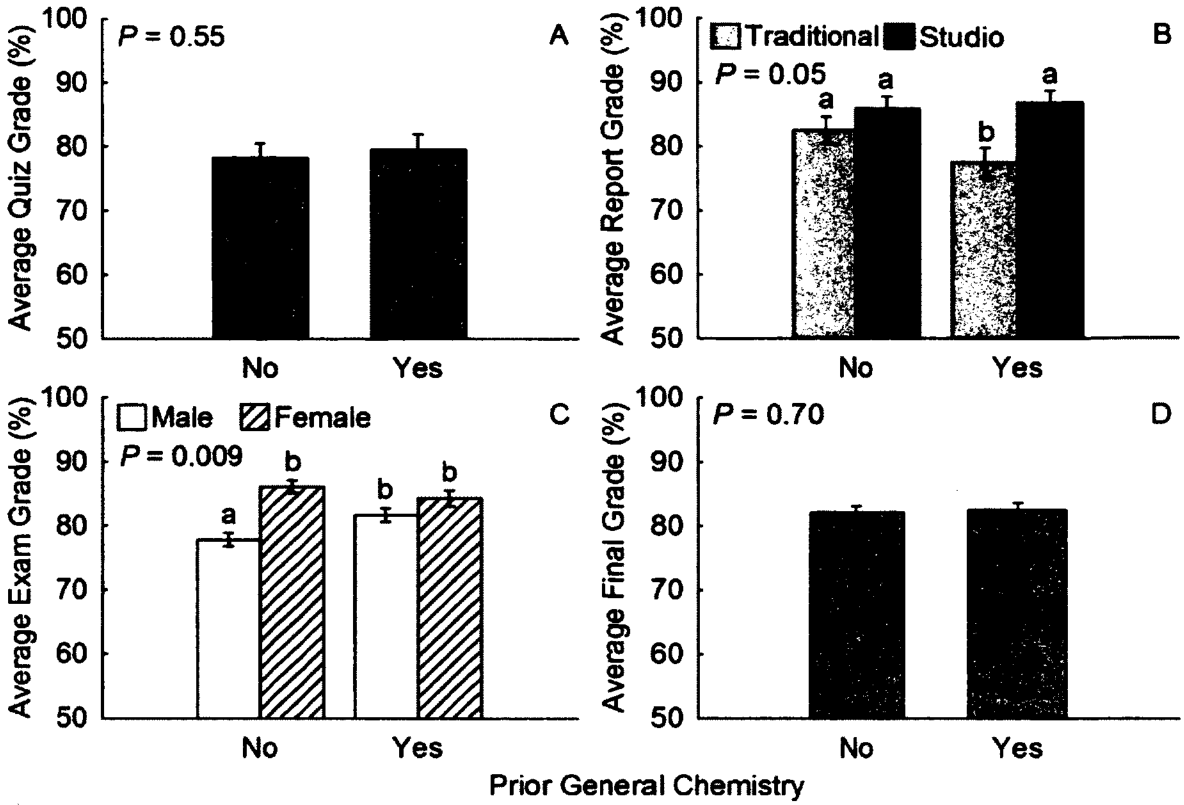


Figure A3.2. The influence of students' chemistry background on their quiz (A), report (B), exam (C), and final grade (D). Note that for reports there was a significant interaction between chemistry background and course structure and for exams there was a significant interaction between chemistry background and gender. N = 176.

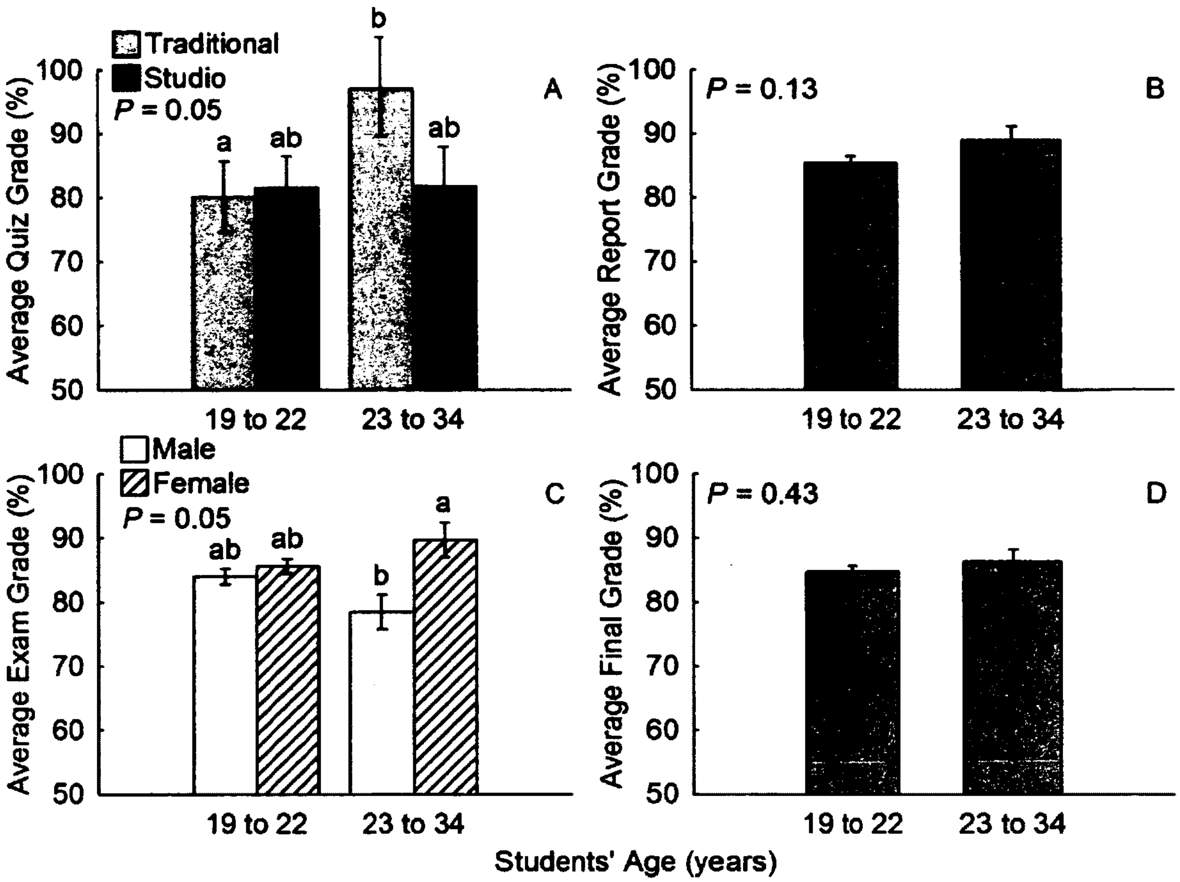


Figure A3.3. The influence of students' age on quiz (A), report (B), exam (C), and final grade (D). Note that for quizzes there was a significant interaction between students' age and course structure, and for exams there was a significant interaction between students' age and students' gender. N = 95.

The Influence of Teaching Assistant on Student Performance

Because there were five different teaching assistants (TA) involved in the three years of the study, and the TAs were responsible for some of the grading (primarily research reports) I wanted to assess whether the TA to which students were assigned influenced students' grades in the course. Unfortunately, while two of the TAs were involved in the traditional year and the first studio year, the other three TAs were only involved in the studio course; thus teaching method (studio versus traditional) is somewhat confounded with TA. To determine if TA influenced students' final grade or their performance on quizzes, reports, and exams, I first performed two-way analyses specifying TA and gender as fixed effects and section (within year) as a random effect. Because no interactions between TA and gender were significant (data not shown) I simplified the analysis to only include TA as a fixed effect (course type was not included with TA because the two were confounded).

I found no difference in students' average quiz or exam grades due to the Teaching Assistant (TA) to which they were assigned (Appendix Table A3.3 and Appendix Figure A3.4 A and C). One TA did assign significantly lower report grades than all of the other TAs (Figure A3.4 B); while the differences weren't significant, the students of TA 2 did also score slightly lower on quizzes and exams, which led to significantly lower final grades for students of TA 2 (Appendix Figure A3.4 D). This TA was involved in the traditional year so it is possible that the lower report and final grades found in the traditional year compared to the studio year (see Figure 3.2 in Chapter 3) could be explained by this low grader. However, because this TA was also a grader in the first studio year, and because the other TA in the traditional year (TA 1) did not generally grade significantly different than the TAs in the studio years, the difference in grades between traditional and studio cannot be due solely to the presence of a low grader in the traditional year. Nonetheless I cannot rule out the possibility that some of the difference is due to the comparatively lower grades assigned to this TAs students.

Table A3.3. Linear mixed effects model F values for one-way analysis of teaching assistant (TA) for all assessment types.

Effect	Quiz	Report	Exam	Final
TA	0.84 ns	11.09**	0.44 ns	5.71*

Notes: Numerator df = 4, denominator df = 6; ns = not significant, * P < 0.05, ** P < 0.01.

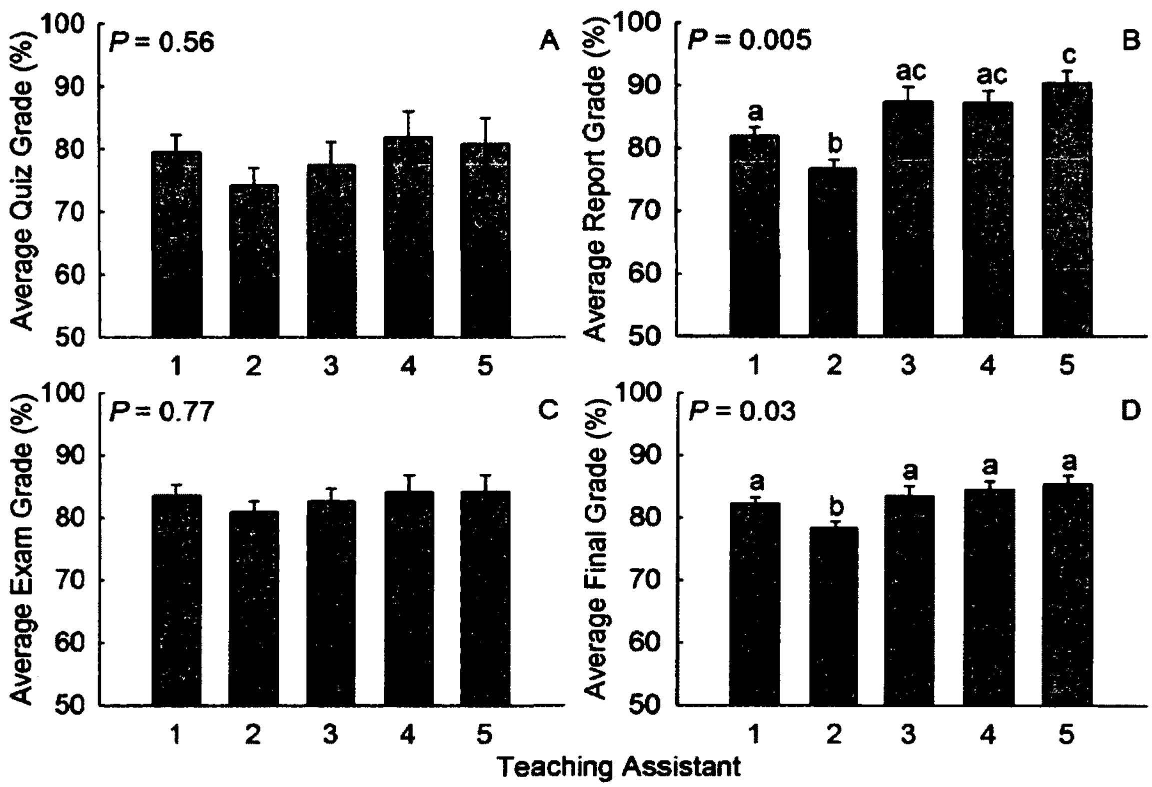


Figure A3.4. The Influence of Teaching Assistant on quiz (A), report (B), exam (C), and final grade (D). Teaching Assistants 1 and 2 aided in the traditional course and the first year of the studio course. Teaching Assistant 3 aided in the first year of studio only. Teaching Assistants 4 and 5 aided in the second year of studio only. N = 213.

Post-Course Retention

Here I include data from the two-year post-course test as this was the only test that students from both the traditional and studio courses completed. While I originally intended to also compare studio students' performance on a one-year post-course test, only 12 out of 57 invited participants from 2010 and 14 out of 56 invited participants from 2011 completed the test (21 and 25% response rate, respectively), which was not a large enough sample size to have confidence in any statistical conclusions (additionally, a comparison of the two studio years was less important than a comparison between the traditional and studio years). Of the 165 students invited to participate in the two-year post-course test, 48 students completed the test (24 each from the traditional and studio courses (13 from 2010 and 11 from 2011)), giving an overall response rate of 29% (46% for traditional and 21% for studio). Because I estimate that some portion of the sample did not receive the invitation letter (based on returned letters with no forwarding address), this is likely a lower-bounds estimate of the potential response rate.

The two-year post-course test (hereafter post-course test) that students completed was identical to the post-test that the 2011 students completed at the end of the course except the post-course test included a brief survey where students listed any soil-related classes or work experiences they had had since completing the course (see Appendix 6 for the post-course test). Students' responses on this survey were classified as no experience (none), only class experiences (class), only work experiences (work), or both class and work experiences (both).

In addition to students' overall score on the post-course test I accessed their confidence on their performance by asking students to select either 'I know this,' 'I'm pretty sure,' or 'I guessed' for each question on the post-course test; a student who mostly guessed would have low percent confidence, while a student who mostly marked 'I know this' would have high percent confidence. This measure of confidence, when combined with a student's correctness for a given question, allowed me to also determine students' misconception. I defined a misconception as getting a question wrong but selecting either 'I am pretty sure' or 'I know this;' thus, a student could have a low percent misconception if they mostly guessed or if they were mostly right.

Because so few students participated in the post-course test I wanted to know whether the participants were representative of their cohorts. Therefore, I first compared the average grades of the post-course participants to the average grades of their cohort (one-sample *t*-test where the post-course test participants were the sample and their full cohort was the population). The post-course participants from the traditional course had significantly higher quiz ($t = 2.72$), report ($t = 4.35$)), exam ($t = 2.67$), and final grades ($t = 4.98$) on average than their cohort (all df = 23, all $P < 0.01$; Appendix Figure A3.5 A). Thus, the post-course participants were on average higher-performing students and do not truly represent the variability of the traditional cohort. While the post-course participants from the studio course also had slightly higher grades on average than their cohort, none of the differences were significant (all df = 23, all $t < 2$, all $P > 0.05$; Appendix Figure A3.5 B), which suggests that the post-course participants were representative of the studio cohort (though there was a marginally significant difference in exam performance: $t = 1.99$, $P = 0.06$).

Because the post-course participants from the traditional course performed better on in-class assessments than their cohort as a whole, I also compared the average grades of the traditional post-course participants to those of the studio post-course participants (linear mixed effects models with grades as dependent variables, course structure as the fixed effect, and section (nested within year) as the random effect; Proc Mixed, SAS 9.3) and found that there were no differences in average quiz, report, exam, or final grades (all F values < 2, all num df = 1, all den df = 6, all $P > 0.10$; Appendix Figure 3.5 C). Because the post-course participants from the traditional course performed better on their in-class assessments than their cohort and because they performed equally well on the in-class assessments as the studio students, traditional students' performance on the post-course test is not necessarily representative of the traditional cohort as a whole, and any differences, or lack thereof, between studio and traditional student performance on the post-course test should be interpreted with caution.

Despite the lack of differences in grades between the traditional and studio post-course participants, I was interested in whether I could detect differences in student performance on the post-course test due to course structure (traditional or studio), students' gender (male or female), or their post-course soil-related experiences (none, class, work, or both). Therefore, I performed separate linear mixed effects models (Proc Mixed, SAS 9.3) for each post-course test metric (score, confidence, misconception), where structure, gender, and experience were used as fixed effects and section (nested within year) was specified as a random effect.

There was a marginally significant interaction between structure and gender for students' post-course test score and a significant interaction between structure and gender for students' percent misconception (Appendix Table A3.4). Male students from the traditional course scored marginally better on the post-course test than female students from the traditional course; for male students there was no difference between those who had taken the traditional course and those who had taken the studio course, but female students' who took the studio course scored marginally better than female students who took the traditional course (Appendix Figure A3.6). Male students who took the studio course had significantly higher average percent misconception than both male students who took the traditional course and female students who took the studio course; there were no differences between male and female students for the traditional course or between course types for female students (Appendix Figure 3.6). There were also no differences in students' percent confidence due to either course structure or gender (Appendix Table A3.4 and Appendix Figure A3.7).

The differences in post-course test performance due to structure and gender were interesting because these differences were the opposite of the gender differences I found for in-class performance: female students generally outperformed male students on in-class assessments in both the traditional and studio structures and where there was a significant interaction between structure and gender (exams), traditional male students performed lower than studio male students and there was no difference between structures for female students (Figure 3.3 in Chapter 3). This suggests that despite higher in-class performance female students who took the traditional course may not retain as much their male peers, though the studio structure may eliminate this gap. On the other hand, despite performing equally well on the post-course test, male studio students were more likely to have a higher percentage of misconceptions (i.e. more likely to get a question wrong when they were confident that they knew the answer). However, these findings should be taken lightly because, as previously noted, the traditional students who took the post-course test are not representative of the traditional cohort as a whole. In addition, the findings for post-course test score were only marginally significant. Therefore, these post-course test findings may not reflect true structure or gender differences in post-course test performance, confidence, or misconception.

Students' post-course soil-related experiences significantly influenced students' post-course scores and their confidence but not their misconception (Appendix Table A3.4). Students who had both soil-related class and work experiences after completing the course performed better (Appendix Figure A3.8 A) and had higher percent confidence (Appendix Figure A3.8 B) on the test than students who had neither class nor work experience. They also had higher percent confidence than students who only had either class or work experiences (Appendix Figure A3.8 A) but there was no difference in performance (Appendix Figure A3.8 B) amongst students who had at least some post-course soil-related experience. Students who had only class experiences also performed better than students who had no soil-related experiences (Appendix Figure A3.8 A) but they did not have higher confidence (Appendix Figure A3.8 B). Students who had only work experience did not perform differently than any other experience type (Appendix Figure A3.8 A). These findings suggest that there is some benefit for students who have had both class and work experiences but the lack of consistent patterns for students who had only class or only work experiences when compared to each other or when compared to students who had no experiences or both experiences make these findings difficult to interpret.

In general my findings suggest that two years after students took the introductory soil course their performance on a post-test and their confidence in their performance depended primarily on whether or not they had soil-related experiences after completing the course, while students' misconceptions related to their performance largely depended on their gender and the course structure. However, because the post-course participants do not truly reflect their cohorts, these findings may not be representative of true differences in post-course performance due to course structure, students' gender, or students' post-course soil-related experiences.

Table A3.4. Linear mixed effect model F values (num df, den df) for main effects (course structure, students' gender, and students' post-course soil-related experience) and significant interactions from models using post-course test metrics (Score, Confidence, Misconception) as dependent variables.

Effect	Score	Confidence	Misconception
Structure	0.33 (1, 5) ns	0.86 (1, 5) ns	0.55 (1, 4) ns
Gender	0.81 (1, 41) ns	1.17 (1, 40) ns	0.17 (1, 41) ns
Structure*Gender	3.73 (1, 39)†	0.00 (1, 41) ns	4.81 (1, 39)*
Experience	4.40 (3, 41)**	5.51 (3, 40)**	1.14 (3, 41) ns

Note: ns = not significant, † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

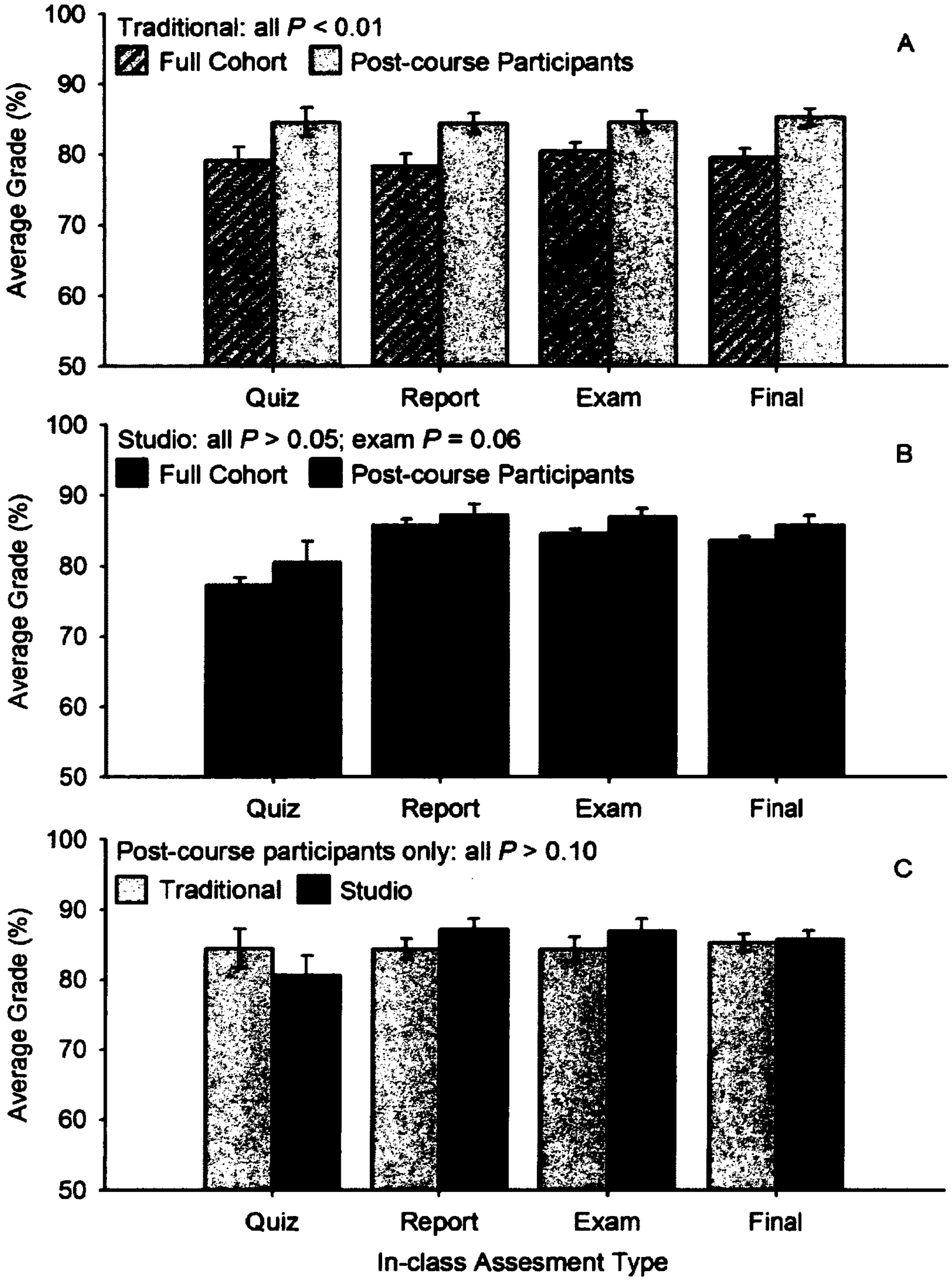


Figure A3.5. A comparison of grades between post-course participants and their cohort for the traditional structure (A) and the studio structure (B) and a comparison of grades between traditional and studio structures for the post-course participants only (C). n = 72 for the traditional cohort, n = 24 for the traditional post-course participants, n = 141 for the studio cohort, and n = 24 for the studio post-course participants.

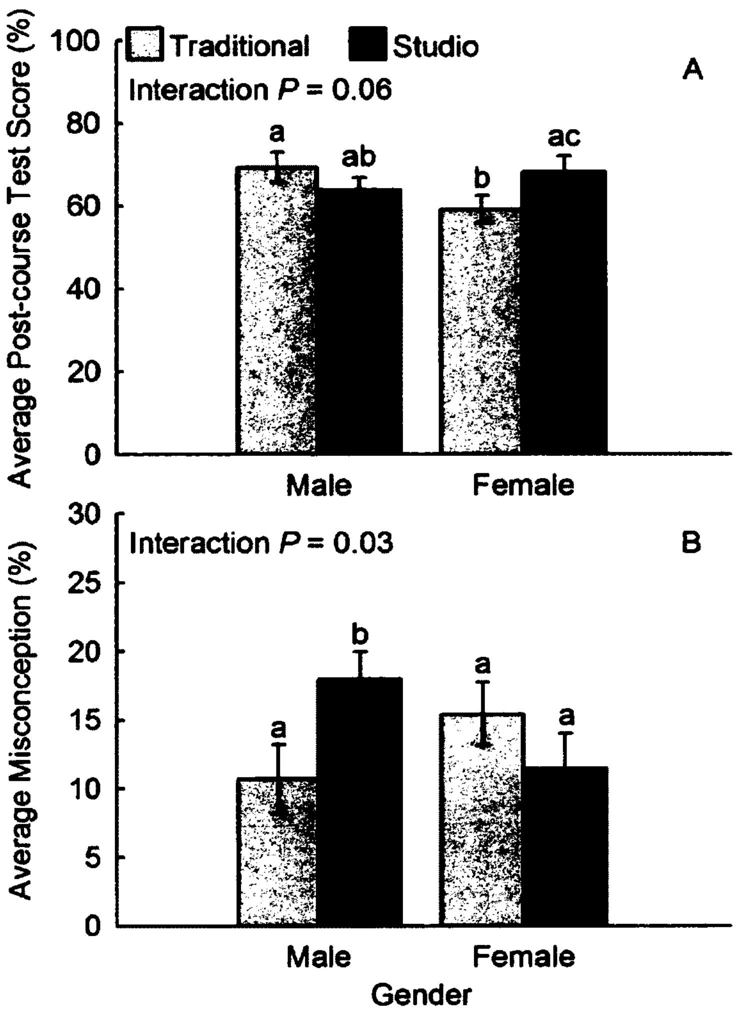


Figure A3.6. The interactive effects of course structure and gender on students' average post-course test score (A) and students' average misconception on the post-course test (B). For A, bars with different letters are marginally significant at $P < 0.10$; For B, bars with different letters are significant at $P < 0.05$. N = 48.

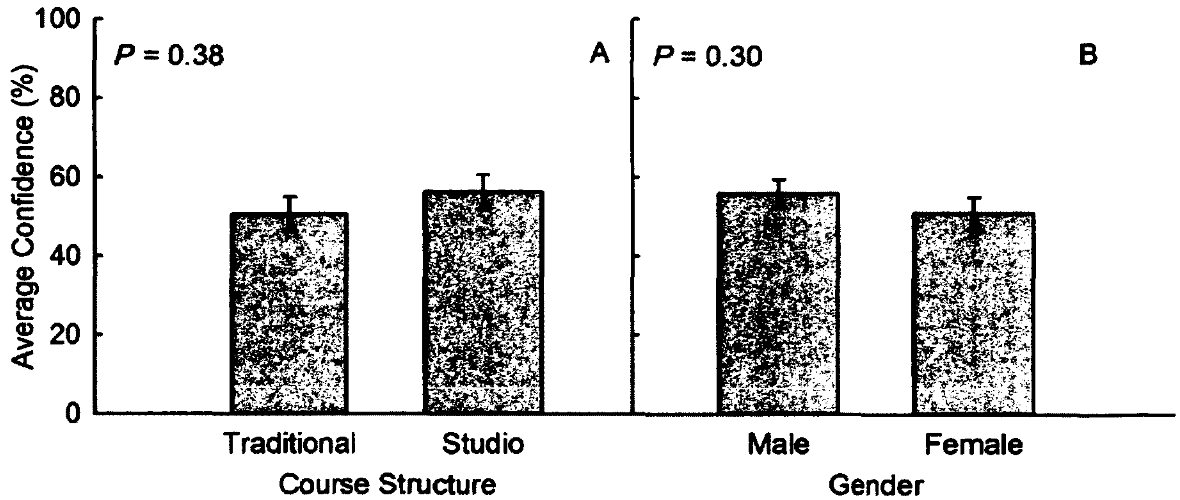


Figure A3.7. The effects of course structure (A) and gender (B) on students' average confidence on the post-course test. N = 48.

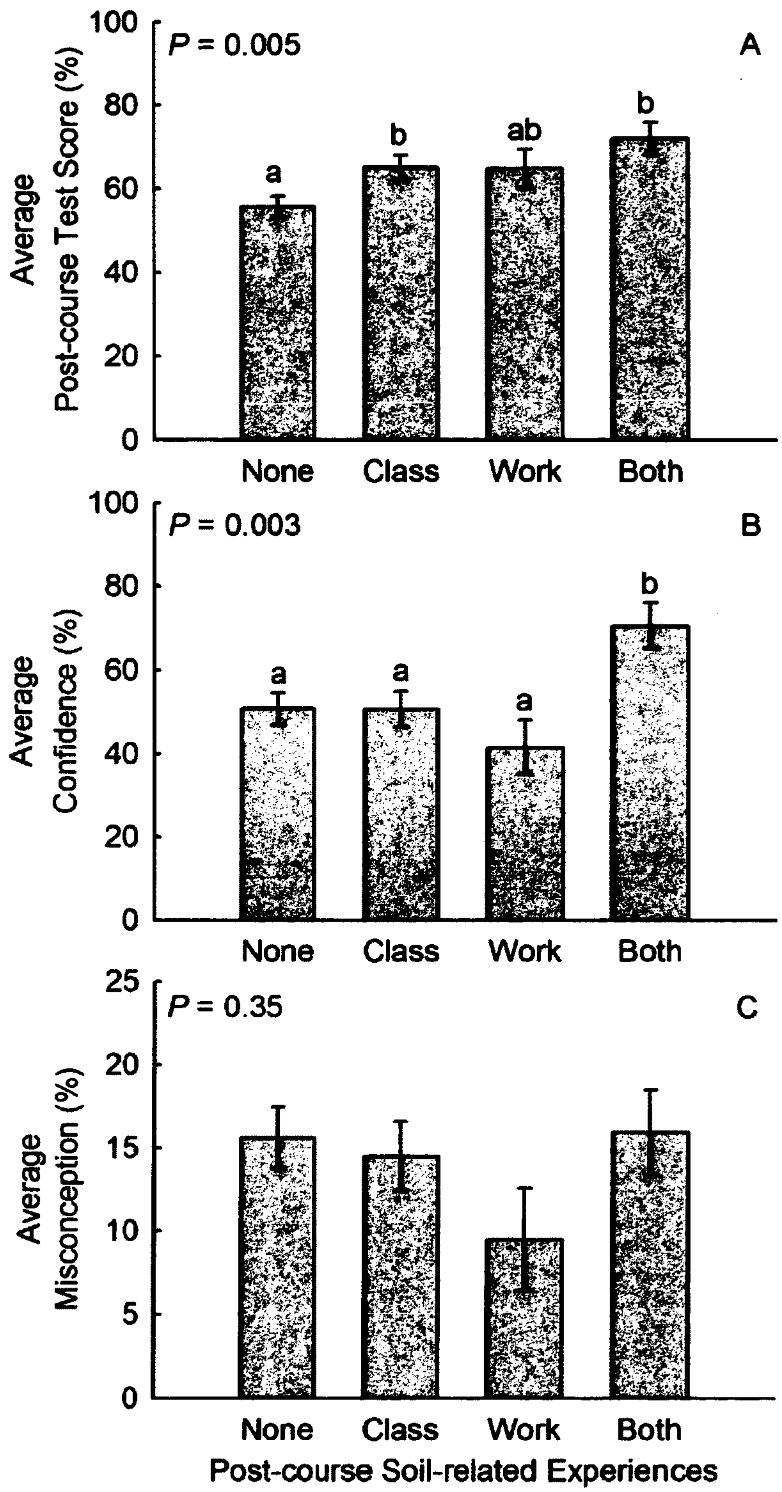


Figure A3.8. The effects of students' post-course soil-related experiences on students average post-course test score (A), their average confidence on the post-course test (B), and their average misconception on the post-course test (C). Within a panel bars with different letters are significantly different at $P < 0.05$. N = 48.

APPENDIX 4: ADDITIONAL MER AND INTERVIEW FINDINGS

Permission to Use the MER

Agreement for Use of the Measure of Epistemological Reflection (MER)
©Baxter Magolda & Porterfield 1982, Baxter Magolda 2000

The following conditions apply to the use of the MER in order to ensure that the instrument is appropriate for the proposed use and interpreted adequately. The MER is copyrighted and thus reproduction or use of the instrument requires written permission. Permission will be granted for its use providing the proposed study is an appropriate use of the instrument and the interpretation is consistent with the interpretation guidelines.

I agree to comply with the conditions below in exchange for permission to use the MER in the study entitled: Are there any relationships amongst students ways of knowing, their performance in, and their perspectives of their experiences in, a collaborative learning studio style course?

The principal investigator(s) will provide a completed MER Usage Proposal Form to request permission for use.

The principal investigator(s) will reproduce the copies of the MER needed in the study. The instrument must be used in its original form and must include the cover page.

The principal investigator(s) will learn the qualitative interpretation process that accompanies the MER and use it to interpret the MER responses, taking care to implement the suggested means for establishing goodness of the interpretation.

The principal investigator(s) agree to provide a summary of the completed study within one year of the completion of data collection.

The principal investigator(s) will not release the instrument to others or utilize the instrument for purposes other than those specified in this agreement.

Name of Principal Investigator: Sarah Andrews Signature: Sarah [signature]

Marcia B. Baxter Magolda [signature]
Marcia B. Baxter Magolda

Date: 5 / 2011

To request permission to use the MER send completed form and Proposal Form to:
Marcia B. Baxter Magolda, Department of Educational Leadership, 350 McGuffey Hall, Miami University Oxford, Ohio 45056; (513)-529-6837

MER and Interview Participant Demographics

Table A4.1. Demographic data for students who completed the Measure of Epistemological Reflection and/or participated in interviews; interview participants are in bold.

Way of Knowing	Pattern	Pseudonym	Gender	YIS	Major	Age	GPA
Absolute	Mastery						
		Charlotte	female	2	FOR	≤ 22	mid
		Dawn	female	2	SAG	≤ 22	mid
		Simon	male	3	FOR	≤ 22	mid
		Lee	male	3	ES	≤ 22	mid
		Jesse	male	3	ECS	≤ 22	mid
		Brian	male	3	ECS	≤ 22	mid
	Receiving						
		Maddie	**female**	**2**	**ECS**	**≤ 22**	**mid**
		Anna	**female**	**2**	**ECS**	**≤ 22**	**high**
		Claire	**female**	**3**	**FOR**	**≥ 23**	**high**
		Lily	female	3	ECS	≤ 22	high
		Camille	female	4	ECS	≤ 22	low
		Eve	female	4	ECS	≤ 22	mid
		Julie	**female**	**4**	**ECS**	**≤ 22**	**mid**
		Elaine	female	4	ECS	≤ 22	high
		Jason	**male**	**3**	**FOR**	**≤ 22**	**low**
		Seth	male	4	FOR	unknown	unknown

Table A4.1, continued.

Way of Knowing	Pattern	Pseudonym	Gender	YIS	Major	Age	GPA
Transitional	Impersonal						
		Virginia	female	2	ES	≤ 22	low
		Leila	female	2	ECS	≤ 22	high
		Celia	**female**	**3**	**ECS**	**≤ 22**	**mid**
		Marion	female	3	ECS	≤ 22	high
		Mel	female	4	SAG	≤ 22	mid
		April	female	4	SAG	≤ 22	high
		Marcus	male	2	FOR	≤ 22	mid
		Nico	male	3	FOR	≤ 22	unknown
		Russell	male	3	FOR	≤ 22	high
		Rich	male	3	ECS	≤ 22	low
		Jake	**male**	**3**	**FOR**	**≥ 23**	**low**
		Dustin	male	3	FOR	≥ 23	mid
		Stephen	**male**	**3**	**ECS**	**≥ 23**	**mid**
		Blake	**male**	**4**	**ECS**	**≤ 22**	**low**
		Clay	male	4	ECS	≤ 22	mid
		Tony	male	4	ECS	≥ 23	low
	Interpersonal						
		Ingrid	**female**	**3**	**ECS**	**≤ 22**	**low**
		Laura	**female**	**3**	**ECS**	**≤ 22**	**mid**
		Daisy	female	3	ECS	≤ 22	mid
		Elena	**female**	**3**	**ECS**	**≤ 22**	**mid**
		Amelia	**female**	**3**	**ECS**	**≤ 22**	**high**
		Molly	**female**	**3**	**ECS**	**≤ 22**	**high**
		Krista	female	4	FOR	≤ 22	low
		Neal	male	3	ECS	≤ 22	high
		Noah	male	3	FOR	unknown	low

Table A4.1, continued.

Way of Knowing	Pattern	Pseudonym	Gender	YIS	Major	Age	GPA
Independent	Individual						
		Gwen	female	3	ECS	unknown	high
		Devin	male	3	FOR	≤ 22	high
		Toby	male	3	ECS	≤ 22	mid
		Brandon	male	4	FOR	≤ 22	mid
		Owen	**male**	**4**	**FOR**	**≤ 22**	**high**
	Interindividual						
		Monica	female	4	ECS	≤ 22	high
		Philip	**male**	**2**	**FOR**	**≥ 23**	**high**
Contextual		**Thomas**	**male**	**4**	**ECS**	**≥ 23**	**high**
No MER							
		Susie	**female**	**3**	**ES**	**≤ 22**	**mid**
		Taylor	**male**	**3**	**ECS**	**≤ 22**	**low**
		Zach	**male**	**4**	**ECS**	**≤ 22**	**mid**

Notes: YIS = Year in School; ECS = Environmental Conservation and Sustainability; ES = Environmental Science; FOR = Forestry; SAG = Sustainable Agriculture. For GPA (grade point average), low ≤ 2.70 (25th percentile), mid = 2.71-3.39, and high ≥ 3.40 (75th percentile).

Code Book

Table A4.2. Code names, descriptions, and examples for categories and subcategories.

Categories and subcategories	Definition and Examples Student...	
Active learning	states or alludes to a belief that being actively engaged in doing, sharing, or thinking was useful	
Doing	describes being active as a form of doing hands-on work	I think most of the lab portion of the class was useful, good stuff, between soil texture exercises, or I remember the aggregate one, just having those were helpful, going out in the field and doing the actual analysis.
	variations: field/lab work, group work	What helped me during tests, I think, was when we had to answer questions on a worksheet, like at certain points we'd have to like fill in and answer- --like, in a class, we'd like answer questions, and then those would kind of like stick in my mind, on a test.
Sharing	Describes benefits of working with peers	if somebody didn't understand something there was always someone who could sit there and help out, who- --who did understand it, and that was good, 'cause I know in a couple- --a couple instances either I or someone else in the group or, you know- --who didn't get it, or <u>did</u> get it, would share that information
	Variations: split the workload, help understand, share ideas, think about things in a different way	I liked the group work, I know a lot of people didn't, but um, I liked it because you can always, um kinda split the work load, and you can get other people's views on things, and it's kinda like "oh, I didn't think about that" type a thing, so it is kinda- --it is helpful. To me anyway.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Active learning, cont.	states or alludes to a belief that being actively engaged in doing, sharing, or thinking was useful	
Sharing, cont.	Describes benefits of working with peers Variations: split the workload, help understand, share ideas, think about things in a different way	But it was good because, like, you just get other people's input and views and it's helpful cause it makes you kind of look at projects, and, um, concepts differently, and look into things that you wouldn't necessarily consider or think about until someone kind of brings it up and describes it for you, so that's helpful. I felt like that was really important to the whole learning process, to understand your peers' perspectives on things as much as your own.
Thinking	describes being more engaged in thinking about the material	I liked that it didn't just end [with] what we wrote down in our journal and like wrote it up in a report- --every day we talked about what different agriculture practices can do and different things like that, and I found that I could apply that in my other classes a lot, and it was really helpful, so, overall really, really good.
Integrated nature of the course	refers directly to the lecture and lab being combined into a single session	
Learning and doing at the same time	states or alludes to a belief that learning in lecture and then immediately applying helps them learn	I feel like this one, whatever we were doing in "lab" always correlated well because we'd essentially talk about it in class first and then immediately do it, and so...it was helpful by, literally talking about it and then immediately doing it, or like the next class talking about it a little bit more and then doing the lab section, it was a lot more helpful and made sense and it actually pertained to the class.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Integrated nature of the course, cont.	*refers directly to the lecture and lab being combined into a single session*	
Better for scheduling	states that the course structure is better for their schedule	I mean, it takes way less time out of my schedule because it's just like, together, for two hours instead of a two hour lab and a lecture, an hour long lecture, which is real nice.
New experience	states that the course structure was a new experience	The structure of it was definitely different than any of my other classes. I didn't have any other studio classes where the lab was combined with lecture, so it was a new experience for me.
	Variations: confusing, different, uncertain, weird	This past semester for Environmental Sociology, for an hour and twenty minutes, and I knew for the entire hour and twenty minutes I'd be sitting here, doing this, but for the whole two hours I don't know what's expected of me, like I...didn't know if on a regular basis, when I'd return to class if we would do a group activity here or there or there. I mean everyone lectures. Like I just- --there's lecture and then there's labs. So lecture you get lectured at, labs you do things, and you guys combined them which is weird to get used to. But I mean, it's good I think, it's just weird.
Community	states or alludes to a belief that interactions with peers and/or instructors has an effect on a sense of community	
Meeting new people	Describes being able to meet more people	...it was just nice to be able to work in groups, 'cause I feel like in a lot of classes you don't end up getting to meet people, and it made- --I don't know, I probably made a friend or two, at least, from the class, which was cool.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Community, cont.	states or alludes to a belief that interactions with peers and/or instructors has an effect on a sense of community	
Approachability of instructors	Describes interactions with instructors that made them more approachable	I really liked that Serita asked "What are your majors, are you Forestry? Environmental Conservation? Science? This? Okay, well here's how this class is going to apply to all of those majors." And it- --it was even done in like a joking way, like "oh you Forestry majors" for certain things, and that was awesome because it was- --it- --you know it was- --it was great, that was a really good thing to do, I liked that.
Being comfortable	Described environment as being more comfortable for interacting and asking questions	I felt more comfortable asking questions because it was going on everywhere and you know, so it was really- --that was good, I liked the group work a lot. ...it definitely helps- --takes like the burden off, and it makes you a bit more willing to, ah, share your thoughts I guess, by being with other people, so that's what I liked about it.
Having fun	Described studio environment as being fun	...you know you'd have the side conversations, in the groups I was in...but you'd be doing the work at the same time...so it made it fun...'cause I guess while you're in that mood you're joking around and you're still doing work and it just makes it fun, it's a fun environment, and I think that's the whole idea behind the class anyway.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Variety of learning and assessment methods	refers to directly or indirectly to the variety of learning and assessment methods used in the course	
Learning methods	states or alludes to a belief that the variety of learning methods helps them learn	I think that the varied nature of the course was actually more helpful than I originally thought it was going to be, because...some of the more memorization-based things that we learned, I picked up better in the lectures, some of the more- --you know how can you teach in a lecture how to do texture ribbons, that's something that you need to actually <u>do</u>; and then you know having worksheet-based stuff for other types- --having a little bit of every sort of learning in there, helped, and I think there was a lot of overlap in that sort of stuff which kinda helped hammer it home...and that was helpful as far as remembering what the heck I'm doing.
Assessment methods	states or alludes to a belief that the variety of assessment methods helps them learn	I like that it's not lecture, lecture, lecture, three exams, good luck, kind of, um, because it doesn't work for a lot of people {laughs} you know, and I'm one of those people and I feel like I- --I don't dread coming to this class, I like look forward to it, and I- --I like that there's so many, not graded assignments, but different ways of evaluating your comprehension and your interest and- --and things like that without having to be so monotonous and giving out an exam.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student…	
Downsides	states or alludes to a belief that an aspect of the studio course was not beneficial, or was inconvenient or stressful	
More field work	expresses a desire for more lab or field work	I mean we did hands-on activities but we only went outside like four times, like I was expecting more of that than what happened, but it was overall good, I think. So that was- --that was the biggest surprise this semester, I thought we were gonna go out a lot more.
Time constraints	states that they felt time constraints because of the structure	I know there was a lot of content to put in such a short amount of time, so, I wouldn't say it was a difficult class in the sense- --the assignments it- --seemed like relevant work and I tried to keep up with it as best I could, but just, you know the classwork itself there was just so much in such a short amount of time I'm sure everyone struggles with it.
Problems with peers	describes drawbacks of working with peers Variations: unequal contribution, too much group work, don't get as much out of it	…in one of my groups, the guy just like wanted to do everything, and like, when the activity was handed out he'd grab it and read it, and then he'd start filling it out, it's like "can I look at that please?" You know? So, I don't know, I just- --I didn't really like that too much …with this last project we did, we had one group member who like- --I'm not gonna say they didn't do anything, but there was a couple a days they were absent, so, it was on me and the other guy to finish it, and that was kind of, I don't know, that was kind of difficult I guess. …in a university, kind of what I like is just hearing from a professional with a lot of experience, whether it's a, you know, grad student or a doctor, so- --instead of just kind of having a study group format in the classroom, you know, I feel like that could be done outside of class, or something. I just don't feel like I get everything I had wanted out of it, you know, with questions and stuff.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Downsides, cont.	states or alludes to a belief that an aspect of the studio course was not beneficial, or was inconvenient or stressful	
Limited lecture	states directly or indirectly that the varied nature of the course limits their lecture time	I would have preferred more of [the mini-lecturing] because it's helpful, I like lecture-based stuff with notes and more of that than filling out worksheets but that's just my weird learning style. I do like my devoted lecture time though, um, I think that's what I really like. Like I think in lab I have a harder time, like understanding things because it's like a lot to connect all at once, so like having the lecture time to like go back and forth, but I don't know that's just me.
Interactions with instructors	describes interactions that detract from feeling a sense of community Variations: don't get to know instructors, not enough interaction with instructor, poor quality of interaction with instructor that hinders comfort	I think the same problem I saw when we did the initial interview, people would be kind of, sort of lax about interacting with instructors, I think that was still going on because I noticed you and some other instructor would always be like, "Well, okay, no questions, alright" {laughs}, you know, it's like...scared, and I- --I really didn't talk too much either so I'm right there with that. I did note that there was less interaction between the instructor and the students...I mean, in other classes that have been smaller I've gotten to know the professor and T A very well because we worked together all the time, um, but I don't- --that wasn't really the case for this course.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Prior experiences	makes a connection between Studio Soils and prior experience	
Different	contrasts Studio Soils to a different prior experience; note that these are also coded at 'new experience' under 'integrated nature of the course' above	
Studio was better	explains how the structure (or other aspect of the course) was better than their prior experience	This absolutely helps with that, because that happens <u>all</u> the time, where T A's are not on the same page as the instructors, or, if that was the case, you know, T A's would need to go to the lectures to make sure that they're material was relevant, because more often than not, it's not. So yeah, I like the studio version a lot. ...my biggest pet peeve is when I go to class and I sit behind kids who are just on laptops with Facebook, or- --or- --or on their phones, it's just- --I get mad when I'm even out to eat with someone and they start to text, so she made that clear, you know, "no electronics" and I liked that because you're here for this class, so let's do this class. ...in other classes too that have been bigger, it's been more that, um, because I don't have that interaction I have to figure it out from the book by myself because the book is your ally, then, but in this case you turn to the people around you, who you're working with anyway, and that- --that was good to have that kind of safety net with other peers, so I liked that actually.
Studio was worse	explains how the structure (or other aspect of the course) was worse than their prior experience	That was one thing they did in that class that was teaching how to do [reports]... they provide the...exemplary reports of what they wanted, um- --comments and everything included, kind of showing, you know, and ah, that seemed to help out a lot. I really like that format of just lecture. Someone just talks to you for an hour and you take notes, it- --I just honestly think that with alternative education- --I've just been doing it for so long that way, it's just harder to break the mold.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Prior experiences, cont.	makes a connection between Studio Soils and prior experience	
Different, cont.	contrasts Studio Soils to a different prior experience; note that these are also coded at 'new experience' under 'integrated nature of the course' above	
Studio was worse, cont.	explains how the structure (or other aspect of the course) was worse than their prior experience	I have two other labs and we went out every single week pretty much, and did stuff, so, there was just a lot more labs in my other classes. I was- --it was just different I don't know, Forest Ecology right now, that's not very hands-on, but I've learned more in that class than <u>any</u> other course...well, it's great PowerPoint. Presentation is everything. Presentation's key.
Similar	compares an aspect of Studio Soils to a similar prior experience	
Positive	describes a positive experience	...kind of like soils, they always brought us outside, like for forest ecology we were always going up and down like ravines, like in College Woods, and like digging up the ground and actually like holding what we were learning about, and that helped a lot. I do think it's like good when, like, the professor goes to labs, I think most of the classes I've learned more when the professor is at the labs, not just the T A, so I think that's what's good about Soils, is that's like a combination, like obviously Serita and you are teaching the <u>lab</u> also with the class, so that's good. ...it definitely works- --the hands-on approach, I like it- --I went to a Montessori school in high school...so you know like hands-on learning definitely helps.

Table A4.2, continued.

Categories and subcategories	Definition and Examples Student...	
Prior experiences, cont.	makes a connection between Studio Soils and prior experience	
Similar, cont.	compares an aspect of Studio Soils to a similar prior experience	
Negative	describes a negative experience	I've noticed that um- --and I don't know if this is something, it seems to be a trend, ah, where- --and it stifles <u>me</u> to ask questions- --that people don't ask questions as much, you know, it's ah- --sometimes even like in ah, Soil Studio, or, Studio Soils, ah, you guys would ask like a question, to the- --to the class, and {laughs} it's just like blank faces, like they're afraid to speak or something, and then it's like, "Well I don't want to be the only one who talks 'cause then I'll look like an idiot or something if I say something wrong" {laughs}. I guess for myself- --group work, I find that I either end up doing a lot of the work singly, or I end up riding other people's coattails where I don't necessarily understand something but I can kinda just swing by it, and then later pick it up for whatever the final project may be- --that has to be done. But that wasn't just for this class in particular, I mean that's just group work as a whole
Competing commitments	explains how a competing commitment (i.e. work, other classes) may have influenced their experience or their performance	...the class, like overall, and maybe it's 'cause it's a sophomore level class, but, like I'm also taking, um, ah, limnology, just like lake ecology, and like, maybe it's just me, but like, it's so complex and like hard, but I feel like I'm doing <u>better</u> in it, almost, just 'cause I know that I have to do it and like stay on top of it, whereas like, I don't know, um, soils maybe got put on the back burner a couple of times just 'cause- --because of that.

Narrative of Studio Soils Students Ways and Patterns of Knowing

Absolute knowing

Students who exhibited absolute knowing showed a belief that all knowledge is certain. Any uncertainty was reflective of the students' lack of knowledge but they still believed that this knowledge was known by someone (i.e. an instructor or other authority figure). For example, Lee preferred facts "because facts are the only answer, and ideas can be interpreted wrong; I have no need to interpret facts, they are what they are." Several students also talked about 'opinions' as for example when Camille expressed a preference for factual information because it "tells the information like it is and doesn't allow for opinions to alter your understanding of it…[but] sometimes ideas and concepts allow for one's own opinions to help them understand the information better." In absolute knowing people may have different opinions on the facts, but the facts themselves do not change.

In general, students who exhibited the absolute way of knowing also viewed instructors as having all the answers and thought that the role of the instructor is to transfer their knowledge to the student. This was most clearly shown when students described their own role as a learner to be to obtain knowledge from the instructor. For example, Anna described her process of learning as "I usually go to class…and I try to take notes and pay attention, and then what I usually do [is] write flashcards, go through my notes, all the definitions, and usually just writing flashcards is enough for me to memorize the information." Students who exhibited absolute knowing viewed only authorities as having all the answers and so peers were not seen as a source of knowledge, though some students explained that peers can be useful in explaining what they've learned to each other. For example, Lee described the usefulness of peers in this context: "because other students can put an instructor's words into laymen's terms; it is easier to understand peers...[but a disadvantage is that you're] not always positive peers are correct."

Patterns within absolute knowing. In general, students who employed the mastery pattern showed a preference for a more verbal interactive approach. They liked to participate in interesting activities that allowed them to aid in mastery of knowledge. For example Lee preferred situations that kept him focused: "[I liked] small lectures that are facts followed by a lab-type learning experience [because] I have a short attention span. Lectures were very to the point and allowed me to focus the whole time."

On the other hand, students who employed the receiving pattern typically showed more of an internal approach to acquiring knowledge; they tended to view listening and recording as their primary role in class and when they talked about peers it was usually in the context of peers helping to make the learning environment more comfortable. For example, Maddie preferred larger lecture classes with more students "because there's always people to answer questions. I mean I answer questions sometimes, but I usually don't, I let the other people answer the questions...I usually don't answer the question unless I know I'm absolutely right." She also appreciated when the environment was comfortable enough to ask questions, but didn't like too much discussion: "I like when you feel it's okay to ask questions but I am not a big fan of discussion...[because] more time can be spent on the material being taught." On the other hand, Jason appreciated small group discussions with peers because he felt more comfortable expressing himself to a small group than in a large classroom setting:

> Group discussion, obviously, is helpful, 'cause usually if some person has a question, someone else is thinking about the same thing and just doesn't want to say anything. That's me usually. I'm trying to speak up in class. I

think that's one of my downfalls, that I have a hard time voicing my opinion I guess, or answering questions.

Transitional knowing

While students exhibiting transitional knowledge still believed that some knowledge is certain, these students accepted uncertainty in some areas. For example, Amelia explained that "Pure facts don't change, whereas an idea or concept can have many facets." In response to the question of whether you can ever be sure if an explanation is correct Molly explained that choosing between two explanations depended on the situation: in factual situations her choice was based on what "fits more with things I've already learned" while in uncertain areas she made her choice based on "which one matches more with my beliefs."

Students exhibiting transitional knowing tended to focus more on understanding knowledge rather than just obtaining it. For example, April describes why hands-on classes help her understand the material: "I prefer hands-on classes where actual work is done and there is minimal lecture time or lecture is given in the field...[because] being able to see, touch, or do whatever I am learning about makes it easier to absorb the material and be able to understand and apply the information."

While information is still obtained from the instructors in transitional knowing, peers were sometimes appreciated because they could help students understand the information. For example, April felt the usefulness of peers depended on whether it was a lecture ("I like it quiet") or lab ("I like involvement"): "I like classes where students don't talk a lot in lecture because it makes it easier for me to focus and not get confused...I can focus more and get correct information...[but] I may not fully understand a topic if there is no discussion." Celia also expressed a preference for working alone but also appreciated peers because "when you just learn by yourself, you're set on what you think and it's not always right, so even if you think you're right, you're not, so having other people help you, I like it."

Patterns within transitional knowing. In general students employing the impersonal pattern were more individually focused: they preferred working alone and getting information from the instructor, emphasized understanding over memorizing, and used logic or research to decide between competing explanations. Peers were discussed only minimally and usually in the context of helping to understand the material. For example, as described above, April focuses on getting information from the instructor during lecture and peers are only mentioned in the context of being involved during labs. She also placed emphasis on understanding and relied on solid facts and evidence to make decisions on competing explanations. Celia also emphasized doing her own research to make decisions between competing explanations and preferred to work alone, though as described above, she did sometimes appreciate peers when they could help her understand the material. She also expected "professors to really care about teaching the students and making sure that they understand the information." Jake also emphasized instructors who were effective at helping students understand rather than ones who just relay information: "I like good lectures where it's not just a constant barrage of information, you know, when the instructor tries to supplement it with examples and things like that. That really helps...if you have examples you can relate it to your everyday life." Jake preferred working alone and learning directly from the professor; he generally did not like working in groups because "I feel that can just get in the way of the work that needs to get done...I don't see why it is necessary to learn the material you're trying to learn."

In contrast, interpersonal students focused more on connections and relationships with others. For example, Neal said "I enjoy close relationships so I feel more comfortable asking questions and participating in class...with more involvement there seems to be more collective creativity and higher morale." Ingrid frequently spoke of the importance of community, particularly when explaining her decision to change her major:

> I didn't really have a sense of community and...I didn't really feel like I could take anything from the soul away from it...and I go to my classes now, as an Environmental Conservation major...and it makes you feel, every day, something new and I love that...I definitely feel more of a sense of belonging, not just to the community at UNH, but to the world too.

Students expressing the interpersonal pattern also spoke more favorably of working with peers and rather than focus on interactions with peers that helped them understand, they tended to focus more on being exposed to new ideas and hearing other's views. For example, Elena felt that "class discussion can bring in new ideas and new ways of looking at a topic." There was often a sense that interpersonal pattern students were just beginning to feel free to express their own voices. This was most evident in Amelia who said "I hate to talk in class, I'm very shy...public speaking makes me uncomfortable." She went on to describe an instructor who made talking in class more comfortable: "I mean he would talk a lot and give lectures but he'd also involve us – 'cause I'm shy and [I usually hate] a class that I'm sitting in where I'm like 'Oh my God please don't pick on me,' but he made it really fun, and he's really helpful, so I really liked his class." She felt that this class helped her with "critical thinking [and] being able to postulate my own ideas." Elena described similar feelings: "I'm pretty quiet and so it is hard for me to speak up in class." However, in contrast to Amelia who described an instructor who helped her express her voice, Elena described a negative experience with an instructor: "I think the environment was stressful, just 'cause...you just kind of felt like you didn't want to talk because the professor a lot of times would not necessarily criticize you but be like 'No that's not right' or 'You're wrong' or something, so it just wasn't a good atmosphere."

Independent knowing

In contrast to transitional knowers who still believed that some knowledge was certain, independent knowers exhibited the assumption that all knowledge is uncertain. Students began to see themselves and their own opinions as being equally valid. In contrast to transitional knowers, who appreciated being able to hear others opinions and ideas, independent knowers talked more about exchanging ideas and viewpoints. Instructors who promote the exchange of ideas and/or encourage independent thinking were valued.

Patterns within independent knowing. Students expressing the individual pattern tended to believe that the reason everything is uncertain is because everyone has their own beliefs. For example, Gwen explained that one can never be sure of what to believe because "everything is based off of personal beliefs and opinions." Individual pattern students also focused more on thinking for themselves and appreciated instructors that used methods that encouraged thinking for themselves and that allowed them to define learning goals. Brandon focused on teaching methods that allowed him to think for himself:

> I believe the most beneficial teaching methods are ones that provide only short lectures then give the students a chance to try the concepts themselves...by being allowed to try the material in a real situation it's much easier to see why a concept works rather than just being told it works...[you should] always pay attention to why something works rather than just being okay with it working.

Devin focused on thinking individually and preferred classes where students had input "because it can steer the topic toward what the students are most interested in knowing. And they can ask specific questions that help them...each student has the opportunity for more individualized learning." Owen explained his preference for thinking individually in the context of dealing with uncertainty: "One must believe one's own explanation. At the end of the day, I must be able to live with myself and my thoughts. If I believe something just because someone told me it was true, I wouldn't respect myself. That's the cheap way out. Think for yourself!"

While students who expressed the interindividual pattern still focused on thinking for themselves, in contrast to individual pattern students who emphasized individual thinking, they focused more on interactions and connections with others. For example, Philip preferred "an abundance of feedback" during classes because "it begins to feel more like a small community...[and] group dialogue often leads to new ideas and perspectives on things that were previously unknown or viewed in a different light." Monica appreciated an open atmosphere: "I like it when students are accepting of others ideas and there is an atmosphere of trust where you can discuss without being shot down." While individual pattern students tended to focus on everyone having their own beliefs, interindividual students usually focused more on interpretation bias, such as when Monica explains that one can never be sure about what explanation to believe because "concepts are all a matter of perspective and observer bias...that changes the way people see things and how things are explained. You can choose to accept one explanation or choose not to accept either...usually the explanation I understand better is the one I go with."

Contextual knowing

Out of the 49 participating students I only found one contextual knower. Thomas spoke of integrating and applying knowledge, and the role that instructors play in the process of learning:

> There is a distinct balance that a teacher has to find between fact and ideas...because in this balance you have a foundation (facts) and something which grows out of them (concepts and ideas). Objectivity and subjectivity must both coincide – neither is exclusive in successful pedagogy...To apply ideas alongside facts is to weave humanity into subjects which often appear cold and abstract. [Instructors should have] a human perspective in sciences; a scientific perspective in humanities. Humor, enthusiasm and creativity take learning about something to

> learning with something...[Instructors and students should] be equal as humans and inferior/superior in subject. There is an inherent inequality between teacher and [student], but none between human and human. Even then the teacher needs the student as much as the student a teacher.

He also recognized that what works for him may not work for others: "Not everyone learns as I do. Some don't want this, they find their balance with different weights." Thomas values interactions with peers but makes a distinction between talking and communication: "[I prefer] plenty of talking. So long as there is communication... unfortunately talking does not necessarily mean communication is taking place." When it comes to evaluation Thomas felt that traditional grade-based assessments did not measure learning. He felt that what should be evaluated is "your achievement and progression through time. Not compared with others, but with personal development. This is impractical, but an actual measure of learning." He felt that certain subjects were portrayed as black and white all the time, which does not match his view on the nature of reality:

> I feel like with sciences and mathematics, generally things come down to being quantitative and that's kind of the fundamentals, that there's a right and a wrong, that there isn't this in between...that you're ignoring, and you're ignorant of, if you think you're a scientist sometimes because I think you want it to be black and white and one way or another but human reality isn't like that, that's not how it works at all.

Narrative of Student Perspectives on their Experiences in Studio Soils

Active learning

All 20 interviewed students spoke about one or more aspects of active learning as something that stood out them. The three sub-categories of active learning are "doing" more hands-on activities (in the lab and/or in the field), "thinking" more about what they were learning, and "sharing" the workload, their ideas, and/or their perspectives.

Doing. Many students spoke generically about hands-on learning. For example, Zach, who went to a Montessori school in high school, believed that a hands-on approach helps learning: "It definitely works- --the hands-on approach, I like it…I just think if you're interactively engaged in something you're learning much quicker." Laura also said that "having our class time be really hands-on was really, really helpful." Other students spoke about lab work, as for example when Jake said: "I think most of the lab portion of the class was useful, good stuff, between soil texture exercises, or I remember the aggregate one, just having those were helpful, going out in the field and doing the actual analysis." Maddie had mixed feelings about field work, she enjoyed the process of analyzing data back in the classroom: "I like the whole process afterwards when you get to do all the data stuff. I like Excel spreadsheets, I'm really good at those, so collecting data and then doing it all back in the lab and then processing it, I like the after parts {laughs}."

Thinking. Many students described how the group activities made them think more about what they were learning. For example, Blake said: "I thought they were all pretty effective…they definitely made you think about all the different topics and…find your own solutions to them, instead of just looking stuff up all the time, which was good." Amelia also felt that working on group activities "makes you think about it, if you come across any problems...it just engages you more." Philip felt that working on group activities "was kind of like giving people the ownership over the process by [saying] 'Okay, this is what you're doing, go ahead, you guys figure it out,' which I think helped out a lot." Other students appreciated how the research projects related well to the what they were learning and allowed them to think about how everything fit together. For example, Jake said: "At the end of the unit it helps wrap everything up that you've kind of learned. It was nice taking that kind of time to reflect and figure out how it all pieces together." Laura felt similarly: "Having the report at the end of each unit synthesized what we went over in each unit, so it was satisfying to actually be able to put everything together and to show that you learned something." Ingrid also emphasized connections between the research projects and in-class discussions: "I liked that it didn't just end [with] what we wrote down in our journal and wrote up in a report- --every day we talked about what different agriculture practices can do and different things like that, and I found that I could apply that in my other classes a lot, and it was really helpful, so, overall really, really good."

Sharing. Many students felt that sharing with their peers helped them understand the material better. For example, Anna explained that "I think the group is good for talking about things, and understanding the different parts of everything we learned." Taylor talked about being able to get help from a peer instead of an instructor: "Some people [who] don't understand some other things wouldn't necessarily have to go to the instructor, or the TA, they could get help from someone in their group." Philip also emphasized understanding:

> If somebody didn't understand something there was always someone who could sit there and help out, who did understand it, and that was good, 'cause I know in a couple instances either I or someone else in the group who didn't get it, or did get it, would share that information....the learning environment just seemed a little more two-way street, everybody kind of, you know, was able to cooperate and get things that way, which was pretty cool, so, I liked that.

In addition to helping them understand the material, other students spoke more about how sharing with peers gave them access to other students' ideas and viewpoints and made them think about things in a different way. For example, Celia spoke about how other students' inputs were better than just learning on her own:

> It's nice to have other peoples' input because sometimes you think that you understand the material but then when you hear the way other people put it, it makes more sense and you can kind of combine your thoughts into a better understanding I guess...I think, I mean at least for me it's easier to learn things when I do see it from other peoples' eyes sometimes, 'cause it- --I mean it gives it like a three dimensional... information...I don't know how to explain it, but when you just learn by yourself, you're set on what you think and it's not always right, so even if you think you're right, you're not, so having other people help you, I like it.

Downsides. However, while many students felt that they were actively "doing," eight students would have liked to do even more field work. For example, Stephen said: "I kind of wish we'd done a little more actual field work, I kinda thought that we might, I don't know if there's really anything else that we could do, but it would have been nice to go out, maybe at least one or two more times throughout the year." Anna expressed similar sentiments:

> It wasn't as much lab stuff as I thought it was gonna be, that's one of the things that surprised me the most, I think. I thought it was going to be more lab, 'cause I'm used to like three hours a week....I mean we did hands-on activities but we only went outside like four times, like I was expecting more of that than what happened...I thought we were gonna go out a lot more.

Most of the students who said they would have preferred more field time also indicated that this was something they would prefer in all their classes, not just Studio Soils. For example, Owen said: "Outside lab time, invaluable, I put that in like every class review thing that I've written...as much time as you can stick people outside and make them do the things that you're trying to teach them, the better."

Students also spoke about problems they encountered working with groups. The most common drawback that students described was that not all students contributed equally to the group activities in class. In some cases this meant that other students did not put in as much effort, leaving the student to pick up the slack. For example, Jason talked specifically about an absentee group member and more generally about having to count on others to do their fair share:

> I don't know {laughs} I kind of like [group work] but then, with this last project we did, we had one group member who like- --I'm not gonna say they didn't do anything, but there was a couple a days they were absent, so it was on me and the other guy to finish it, and that was kind of difficult I guess. Other than that I think it works, the group learning, you just gotta make sure everybody participates....That's the problem, is you're... basically counting on that person to come, and do their fair share, and...I don't know, some groups maybe get the whole distributing the workload better than others.

Zach talked more about how shy people who do not contribute as much to discussion can be frustrating:

> I've had shy people complain about me before 'cause I kinda just took the whole spotlight because I was like "well God, if no one's gonna do it, if they're not gonna say anything then I'll keep going." And, last group I just ended up doing a bunch of the work, they never really wanted to discuss anything, which I <u>hate</u>, and why I generally take the leadership role in most my labs, so I can ask certain questions so I can understand the information. So I kinda hate when my group mates don't say anything.

On the other hand, other students described situations where one group member took control and did not allow them to contribute as much as they wanted to. For example, Claire said:

> There was probably one of these in every class, but in one of my groups the guy just wanted to do everything, and when the activity was handed out he'd grab it and read it, and then he'd start filling it out. It's like "Can I look at that please?" So, I don't know, I didn't really like that too much, but other than that all my groups were pretty cool.

When students' did not contribute equally it was primarily seen as frustrating rather than something that hindered their learning. However, a few students described occasions where they did feel that working in groups sometimes hindered their learning. Only one student really felt that working in groups hindered his learning more than it helped. While Jake did say that sometimes working in groups can be helpful ("there's times where if I need a little bit of help I can just ask someone in my group to maybe explain it a little and vice-versa"), he primarily felt that working in groups during class time prevented him from learning as much from the instructors:

> I find that I either end up doing a lot of the work singly, or I end up riding other people's coattails where I don't necessarily understand something but I can kinda just swing by it, and then later pick it up for...the final project that has to be done. But that wasn't just for this class in particular, I mean that's just group work as a whole, but seeing how this class is a lot of group work, I can find that probably happen a lot. Also, I think there was one exercise where basically we did the required reading, and then we went around to different groups and went back through the required reading as individuals who had studied each part, in those cases where it's- --you know, in a university, kind of what I like is just hearing from a professional with a lot of experience, whether it's a grad student or a doctor, so- --instead of just kind of having a study group format in the classroom, I feel like that could be done outside of class, or something. I just don't feel like I get everything I had wanted out of it, with questions and stuff....I mean, that was the one thing where it's like, you know, you put all this money towards an education and you just kind of expect the professionals to teach you what they know from their experience, so, it just felt more like a peer-group kind of deal where I could do that at the library or something.

Integrated nature of the course

While most students described the combined nature of the studio course as being helpful for their learning, many students focused on logistical aspects which could be positive (better for their schedule) or negative (time constraints).

Learning then doing. Many students found the integrated structure very helpful because they learned about something and then were immediately able to apply it. For example, Laura said: "having the field work, literally like melt into the lectures that we had in class and have our class time be really hands-on was really, really helpful." Several students contrasted their experiences to their prior (or concurrent) experiences in traditional lecture-based courses with a separate lab. For example, Celia said:

> I feel like this one, whatever we were doing in "lab" always correlated well because we'd essentially talk about it in class first and then immediately do it...I had a class this semester where we would, you could say learn

> about it in lecture and then four days later have a lab about it but it never matched up correctly and then once you were done with the lab it was just over and you wouldn't talk about it again. So it was really frustrating, 'cause it was kind of confusing as to how it was just thrown in. So yeah, this one was a lot more helpful...by literally talking about it and then immediately doing it, or the next class talking about it a little bit more and then doing the lab section, it was a lot more helpful and made sense and it actually pertained to the class.

Blake also contrasted Studio Soils to classes where the lab was separate:

> I think because they're together it makes it a lot easier to learn, because with the mini-lecture you learn about the topic real quick and then you do an activity about it. So it's not like I'm...cramming all this information in and then three days later going to a lab where I forgot what I learned at the beginning of the week... So I definitely think the studio way makes it easier to do that.

Julie described similar feelings when comparing Studio Soils to her ecology class:

> What was hard about that was that we'd learn something in class and we'd have to apply it to the lab and then I'd forget what we had learned in class, 'cause it was a lecture and...I'd be maybe paying attention, maybe not, like falling asleep or something, depending on the day. So I think having them separate kinda just breaks up your mind, and then when you go to lab you're like "Why am I learning this again?" But then, when it's together, like this, we just learned it and now we're gonna be talking about it and [doing] different things, so that's really helpful for me.

Better for scheduling. In addition to speaking about how the integrated structure helped their learning, many students appreciated that it was combined for the simple fact that it was better for their schedule. For example, in addition to helping her learn, Laura also said: "I mean it takes way less time out of my schedule because it's just together for two hours instead of a two hour lab and an hour long lecture, which is real nice." Other students focused more on the gap between lecture and lab in traditional classes. For example, Maddie said:

> I do kind of like it that you don't have a separate lab time, 'cause that's always kind of annoying to me because most of the labs are in the afternoon so you usually have a gap between your morning classes and your afternoon classes, and I prefer just to get it all done at once {laughs}. So yeah, I did kind of like that they were together, like lab and class.

For most of these students, having the lecture and lab combined was a convenience that they appreciated, but Ingrid focused more on how classes with a separate lab can be stressful:

> I mean going back to what I said earlier about a students' time availability...last spring I was in three courses and each one had a three hour lab so I'd...have nine hours of lab a week, and then...three hours [for lecture], so I was just like "Group project? When?" you know, and that was really frustrating, so I would prefer the soils' studio set-up for future science classes.

New experience. Several students described how the studio structure was a new experience for them in contrast to all their prior classes. For some students, like Julie, this was seen as a good thing:

> This class, like, at the end- --at my senior year I finally get a class that really helps me learn something, and I hope that other classes do it more. I think that people are picking up on it, 'cause it's been that way- --the lecturing style has been that way forever and that's just been kinda the default, what people have known. So, yeah, overall it definitely helped me, and then like my grade, definitely reflected it {laughs}.

On the other hand, in contrast to Julie, Jake expressed difficulty overcoming the style of learning that had typified his prior experiences: "I guess years and years of using that system where I've just been taught things, you know, it's hard to break the mold again." Other students described more mixed feelings, often describing the experience as "weird." For example, Anna said: "I mean everyone lectures. Like I just- --there's lecture and then there's labs. So lecture you get lectured at, labs you do things, and you guys combined them which is weird to get used to. But I mean, it's good I think, it's just weird." Maddie described similar feelings: "Sometimes there's lecture in lab which I think is kind of strange, but like, that's why I kind of like Studio Soils because it's the lab and lecture mixed which I've never had before, which is kind of interesting." Owen also thought Studio Soils was a weird experience:

> Well, you did say you can't be offended so the thing that stood out- --this was a weird class. It was- --I've never taken a class that was set up like

> this. Everything about it was...unique, it was- --yeah, it was- {laughs} --words are failing- --um, the class structure...was an odd length of class, halfway between a lecture and a lab, it was an odd class as far as what you did on a day to day basis, how groups were broken up, just the whole thing was very different from any other class that I've taken.

In some cases, the unfamiliarity of the studio structure compared to their prior experiences caused stress and anxiety in students, primarily related to uncertainty over what was expected of them. This was expressed most strongly by Ingrid:

> I liked the labs but I- --I didn't- --understand, like the class was from ten to twelve, and there were some times where it'd be not lecture but we would do like in-class activities...and then one day it would be an hour lecture and an hour lab, so I didn't understand like, if it was one hour just like concepts and stuff and then another hour application, or things like that, that was a little confusing... the uncertainty of how the time would be spent, for the two hours...like this past semester for Environmental Sociology...I knew for the entire hour and twenty minutes I'd be sitting here, doing this, but for the whole two hours I don't know what's expected of me, like I didn't know...how the time was [going to be] spent.

<u>Downside: Time constraints</u>. Three students focused more on time constraints, and felt that because the lecture and lab were combined, there was often too much to do and not enough time. For example, Thomas said: "I liked [the lectures] but I felt like they were sort of compacted, they were sort of rushed because of the way things were set up, there was so much to get done in such a short period." Of the students who felt restricted by time constraints, Jake felt the most strongly:

> The class structure itself, it took some getting used to I think, from the beginning, I know there was a lot of content to put in such a short amount of time...the assignments seemed like relevant work and I tried to keep up with it as best I could, but just, you know the classwork itself there was just so much in such a short amount of time I'm sure everyone struggles with it....in a two hour stretch where you're trying to fit in the material on top of the lab, and you're just kind of always really pushed...I just feel like it makes things more chaotic...it can be hard sometimes.

While three students did describe sometimes feeling time constraints, only Jake and Thomas felt that overall the combined lecture-lab was not particularly helpful. When Thomas heard about some of the feelings of disconnect between lecture and lab that other students had experienced he said: "I don't really think that was the case in my experience. And I think that it's not like I forgot everything within a day of having the lecture, or wouldn't have if it was separated between two days, but I guess maybe that's different, maybe it doesn't make sense to other people."

Community

Many students spoke of interactions with peers and instructors that related to fostering a sense of community and a positive work environment.

Meeting new people. Many students enjoyed switching groups multiple times because they got to meet more people and make friends. For example, Laura liked switching groups because "getting to know the people in the class is really important to me. I feel like I know basically everybody in my major now." Taylor also emphasized getting to know everyone in the class: "I would say that I got to meet, almost everyone in the class, whereas I haven't ever really in a lecture...I met a few people in our major that I never had the opportunity to meet, so that would probably be the one thing that stood out the most." Stephen particularly appreciated meeting people because as a commuter he did not always get the opportunity:

> Another definite positive for me anyways, is that I'm a commuter and I don't really meet a lot of people, so...I liked switching lab partners, I know a lot of kids probably don't like that, but...I don't really get to meet a lot of people so it's definitely a way to meet people. Even though, I mean I'm not looking to meet close friends or anything, but just someone that I can say hi to or something, you know, so I really liked that.

Approachability of instructors. In addition to peers contributing to a sense of community, some students also felt that the structure of the class and the instructors helped create a community as well. For example, Jason felt that he got to know his peers and instructor better:

> Well...you kinda get to know your class a little better, I don't know if that's one of the goals or whatever, but yeah, I feel like I got to know my TA

> better than if I was in a lecture hall with two hundred and some odd people, when you're just a number in a book...so I prefer the studio style over the traditional lecture and lab.

Ingrid spoke of a particular instance where an instructor's attitude contributed positively to the course:

> I [also] really liked that she asked "What are your majors, are you Forestry? Environmental Conservation? Science? This? Okay, well here's how this class is going to apply to <u>all</u> of those majors." And it was even done in like a joking way, like "oh you Forestry majors" for certain things, and that was awesome...it was great, that was a really good thing to do, I liked that.

<u>Comfortable</u>. Blake focused on how working with people contributed to the positive environment and helped his learning process:

> ...it helps a lot to learn because everyone's, you know, positive-minded [and] has good feelings about it and they're not just stressed and angry and wanna get out... they actually want to sit down and learn...which is cool...and it definitely...makes you a bit more willing to share your thoughts I guess, by being with other people, so that's what I liked about it.

Ingrid also described feeling more comfortable because the class felt like a community: "I feel like I don't dread coming to this class, I like look forward to it...and the people who are in this class, they've all had classes together before, and it's nice, and I feel like it's a close-knit environment."

<u>Having fun</u>. Philip spoke about group work lightening the mood and making the environment more fun: "You know you'd have the side conversations, in the groups I was in...but you'd be doing the work at the same time...so it made it fun...'cause I guess while you're in that mood you're joking around and you're still doing work and it just makes it fun, it's a fun environment."

<u>Downsides</u>. While many students liked switching groups because they got to meet more people, several students would have preferred to stay in the same group or switch less often because as Owen said: "When you have to split up into so many groups you don't ever really get to know anybody." Julie also would have preferred to change

groups less often because: "you get kind of attached, or I don't know, you build a relationship with this group of people, and you maybe work well together and you're like 'Oh, well, I liked how this group works.'" Other students focused more on a lack of interaction with the instructors. Thomas felt like he had more peer-to-peer interactions than face time with the instructors, which he actually liked in some ways, but he felt like this meant he didn't get to know the instructors as well as in other classes:

> I did note that there was less interaction between the instructor and the students...I could see some people having a tough time with that and wanting more face time, but it's a big class, and I think that's just the nature of it to not talk so much with the person directly. I mean, in other classes that have been smaller I've gotten to know the professor and T A very well because we worked together all the time, but that wasn't really the case for this course.

Philip felt that in class discussions where the instructors would try and engage students his peers were perhaps afraid to speak up in class, which he felt inhibited him from speaking up as well:

> It stifles <u>me</u> to ask questions- --that people don't ask questions as much, you know sometimes...you guys would ask a question to the class, and {laughs} it's just like blank faces, like they're afraid to speak or something, and then it's like, "Well I don't want to be the only one who talks 'cause then I'll look like an idiot or something if I say something wrong" {laughs}. I don't understand where that comes from, 'cause I know everybody has questions, but that's probably the only negative thing I find.

<u>Variety of learning and assessment methods</u>

While variety was not referenced as many times as interactions, active, and integrated several students did speak about the variety of learning and/or assessment methods used in the course; most students appreciated this variety but some did feel like it meant that there was not enough time for lecture.

<u>Learning methods</u>. Many students described their appreciation for the variety of learning approaches used in the course and felt that it was well-balanced. For example, Elena said: "I thought that there was a pretty good balance of hands-on stuff and

lecture stuff, so that was good." When asked if any component stood out as being the most helpful, Celia responded:

> I thought it was all helpful. 'Cause there was never too much of one. It was like, well-balanced so you were never- --like I get distracted during long lectures, so it was good that like- --I mean like once a week maybe there was an hour worth of lecture and the rest was kind of, like doing paperwork, or going through the book and finding answers for things, or talking in a group to understand the concepts we were talking about. So I think it was all helpful, I don't think one thing stands out more than the others, it was just- --it was nice that they were all equally balanced.

Owen also spoke about the variety of learning methods:

> I think that the varied nature of the course was actually more helpful than I originally thought it was going to be because...some of the more memorization-based things that we learned, I picked up better in the lectures, some of the more- --you know, how can you teach in a lecture how to do texture ribbons? That's something that you need to actually do, and then you know having worksheet-based stuff for other types of [learning], having a little bit of every sort of learning in there helped, and I think there was a lot of overlap in that sort of stuff which kinda helped hammer it home, you know, well you got lectured on this on Monday and then on Wednesday you went and you did some worksheet based on the same thing and then the next Monday you had to read about it, and that was helpful as far as remembering what the heck I'm doing.

Assessment methods. Other students spoke more about the variety of ways their learning was assessed. For example, one thing that stood out to Ingrid was:

> I like that it's not lecture, lecture, lecture, three exams, good luck, because it doesn't work for a lot of people {laughs} you know, and I'm one of those people and...I like that there's so many, not graded assignments, but different ways of evaluating your comprehension and your interest and- --and things like that without having to be so monotonous and giving out an exam.

Downside: limited lecture. In contrast to the students who appreciated the variety of the course, some students thought that this variety limited their lecture time. Most of these students liked that the lectures were shortened and to the point but they would have preferred a few more. For example, Maddie said:

> I would have preferred more frequent [mini-lectures] because I think they were actually a really good length. Like it wasn't like you guys were

> talking for two hours, which would be hard. For the most part I liked the length because it was short and to the point and that way you could get all the information but…there was still time to do like activities and stuff. But I was surprised that there wasn't more.

Laura would have also preferred more mini-lectures:

> I liked [the mini-lectures] a lot. When we did the mid-semester evaluations I voted to have some more mini-lectures, but even after that I noticed that the flow was better from lecture to activities, which was good. But I think definitely keep mini-lectures, put a couple more in if possible but they were really fine the way they were.

Quantitative relationships amongst student performance, attitude, and ways of knowing

My original objective for the research presented in Chapters 3 and 4 was to look for relationships amongst student attitude, performance, and ways of knowing. However, because of the low number of participants (49 completed the measure of epistemological reflection (MER) and 20 participated in interviews), a robust statistical analysis was not possible. The findings from the quantitative analysis may however be interesting in terms of sparking further research and so they are presented here.

Statistical analyses

Contingency tables (Freeman-Halton extension of Fisher's exact probability test) were used to test whether there were differences in way or pattern of knowing by any of the following categorical demographic characteristics: gender (male or female), major (Environmental Conservation and Sustainability or Other (Forestry, Environmental Science, and Sustainable Agriculture)), age (19-22 or 23-34), or year in school (2nd, 3rd, 4th). Note that I divided age into categories (equivalent to traditional and non-traditional status) in order to protect students' identities. Because only one student was found to exhibit the contextual way of knowing, these analyses only consider absolute, transitional, and independent knowing. Because of the low number of participants, the specific patterns within each way of knowing were not considered in these analyses; rather, the mastery, impersonal, and individual patterns were combined into the "separate" pattern type, and the receiving, interpersonal, and interindividual patterns were combined into the "connected" pattern type.

Student attitude was described by three metrics (calculated from their initial and exit interviews): total number of positive references ("liked," "fun," "interesting," "helpful," etc.) total number of negative references ("didn't like," "confusing," "frustrating," "tedious," etc.), and percent of references that were positive (used to classify each student as exhibiting a primarily positive (≥60% positive), negative (≤40% positive), or neutral (41-59% positive) attitude toward the course). Note that the two students who did not consent to audio recording were not included in analyses using student attitude. Student performance metrics (average quiz, report, and exam grades and final course grade) are described in Chapter 3. Linear mixed effect (LME) models were used to determine whether there were relationships between student performance and ways or patterns of knowing (N = 49) and between student attitude and ways or patterns of knowing (N = 15); section was specified as random in all LME (proc MIXED, SAS 9.3). Relationships between student attitude and performance were analyzed by Pearson correlations (N = 18; proc CORR, SAS 9.3).

Findings

There were no statistical differences between students' way of knowing (absolute, transitional, independent) and their gender, major, age, or year in school (Appendix Table A4.3). There were also no statistical differences between students' pattern type (separate or connected) and their age or year in school (Appendix Table A4.3). However, there was a significant difference in students' pattern type with gender (Appendix Table A4.3): men were more likely to express the separate pattern type than the connected pattern type and women were more likely to express the connected pattern type than the separate pattern type (Appendix Figure A4.1 A). There was also a marginally significant difference in students' pattern type with major (Appendix Table A4.3): students majoring in Forestry, Sustainable Agriculture, and Environmental Science ("Other" in figure) were more likely to express the separate pattern type than the connected patterns and students majoring in Environmental Conservation and

Sustainability were slightly more likely to express the connected pattern type than the separate pattern type (Appendix Figure A4.1 B).

The total number of positive references (371) made by students during their exit interviews far exceeded the total number of negative references (242; Appendix Figure A4.2, left). For a given student an overall positive attitude towards the course was defined as having ≥ 60% positive references, while an overall negative attitude was defined as ≤ 40% positive references (neutral = 41-59%). Half of the interviewed students exhibited an overall positive attitude toward the course, while only one sixth exhibited an overall negative attitude toward the course; the remaining third exhibited a neutral attitude (Appendix Figure A4.2, right).

Student exam performance was significantly related to way of knowing and marginally significantly related to pattern type (Appendix Table A4.4 and Appendix Figure A4.3); report and final grades were also marginally significantly related to pattern type, but there were no significant relationships between way of knowing and quiz, report, or final grades, or between pattern type and quiz grade (Appendix Table A4.4; data not shown). There were also no significant relationships between student attitude metrics (number of negative references, number of positive references, and percent of references that were positive) and either way or pattern of knowing (Appendix Table A4.5; data not shown) or between student attitude metrics and performance metrics (Appendix Table A4.6; data not shown).

Discussion

I did not find any statistically significant relationships between students' ways of knowing and their attitudes about the course or between students' attitudes and their performance. This may at least partially be due to the low number of participants making it difficult to make statistical comparisons. In addition, I quantified students' attitude by tallying up the total number of positive and negative references students made, which may not accurately represent students' true attitude. In contrast, Lo and Monge (2013) administered student feedback surveys to 82 students over two years to more accurately measure student attitude in an active-learning social problems class and found that students' satisfaction with the course and with group activities was related to student learning, but the relationship was stronger for students' perceived learning than it was to their actual final grade.

Past research suggests that many students, particularly transitional interpersonal and independent interindividual knowers, turn away from science to other disciplines because they "view it as cold, inhuman, dogmatic, manipulative, and the enemy of the intuitive subjective knowing they believe in" (transitional interpersonal) or because they "tend to have a harder time adapting to academic demands" in a traditional curriculum that is more compatible with the individual patterns (independent interindividual; discussed by Felder and Brent 2004a). Ingrid, who expressed the interpersonal pattern within transitional knowing, clearly portrayed this feeling when describing her motivation from switching from Environmental Science to Environmental Conservation and Sustainability. Experiences such as these may explain the marginally significant relationship I found between students' major and pattern of knowing.

Because there were more women in the connected pattern type, the marginally significant relationships between gender-related patterns and exam, report, and final grade (i.e. connected pattern type students performed better) may be explained by the finding that in this course female students outperformed male students (see Chapter 3).

Conclusion

Performance on exams was significantly related to students' way of knowing and students' final grade and their performance on exams and reports were marginally significantly related to their pattern type. There were no other statistically significant relationships between students' perspectives, performance, or ways of knowing. There is some evidence that students' majoring in one of the applied science majors (forestry, environmental science, and sustainable agriculture) were more likely to express the "separate" pattern type, while students' majoring in policy (environmental conservation and sustainability) were more likely to express the "connected" pattern type.

Table A4.3. Chi-square (df), *P* values for contingency table analyses of way of knowing or pattern type and demographic characteristics.

	Gender	Major	Age	YIS
Way of knowing	1.92 (2), 0.46	1.40 (2), 0.85	1.08 (2), 0.59	4.38 (4), 0.49
Pattern type	8.70 (1), 0.004	3.50 (1), 0.08	0.22 (1), 1.00	0.37 (1), 0.85

Notes: Gender = male or female; Major = Environmental Conservation and Sustainability or Other (Forestry, Environmental Science, and Sustainable Agriculture combined); Age = 19-22 or 23-34; YIS (Year in School) = 2nd, 3rd, or 4th. For 2x2 tables (gender, major, and age by pattern of knowing) Fisher's exact probability test was used; for 2x3 and 3x3 tables (all others) the Freeman-Halton Extension of Fisher's was used.

Table A4.4. Linear mixed effect model F values for effects of way of knowing and pattern type on student performance metrics (quizzes, reports, exams, and final grade).

Effect	Quiz	Report	Exam	Final
Way of knowing	0.26 ns	1.20 ns	3.18 *	1.76 ns
Pattern type	1.62 ns	3.39 †	3.03 †	3.48 †

Notes: For way of knowing num df = 2 and den df = 43; for pattern of knowing num df = 1 and den df = 43; ns = not significant, †$P < 0.1$, * $P < 0.05$.

Table A4.5. Linear mixed effect model F values for effects of way of knowing and pattern type on student attitude metrics (number of negative references, number of positive references, and percent of references that were positive); neither effect was significant for any of the metrics.

Effect	# Negative	# Positive	% Positive
Way of knowing	1.90	0.25	0.63
Pattern type	0.01	0.00	0.01

Notes: For way of knowing num df = 2 and den df=10; for pattern of knowing num df=1 and den df=10.

Table A4.6. Correlation coefficients for relationships between student attitude metrics (number of negative references, number of positive references, and percent of references that were positive) and performance metrics (average quiz, report, and exam grades and final course grade); no correlations were significant.

	Quiz	Report	Exam	Final
# Negative	0.24	0.39	0.21	0.36
# Positive	0.21	0.04	0.12	0.10
% Positive	-0.05	-0.33	-0.04	-0.23

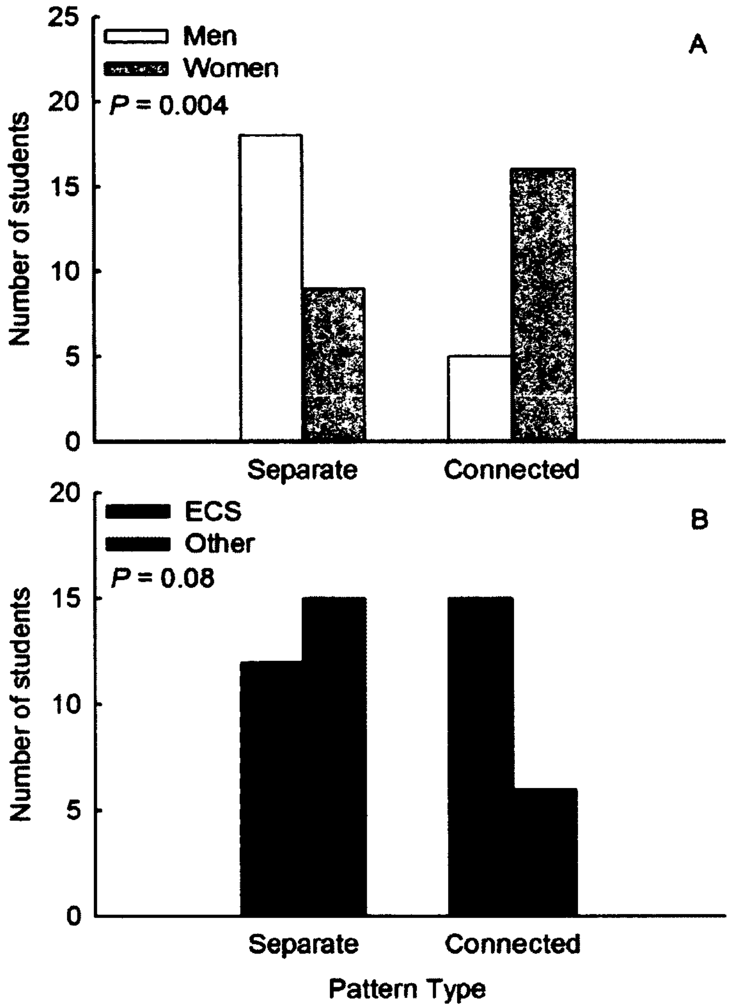


Figure A4.1. Number of students expressing separate and connected pattern types by gender (A) and major (B). ECS = Environmental Conservation and Sustainability; Other = Forestry, Sustainable Agriculture, and Environmental Science combined.

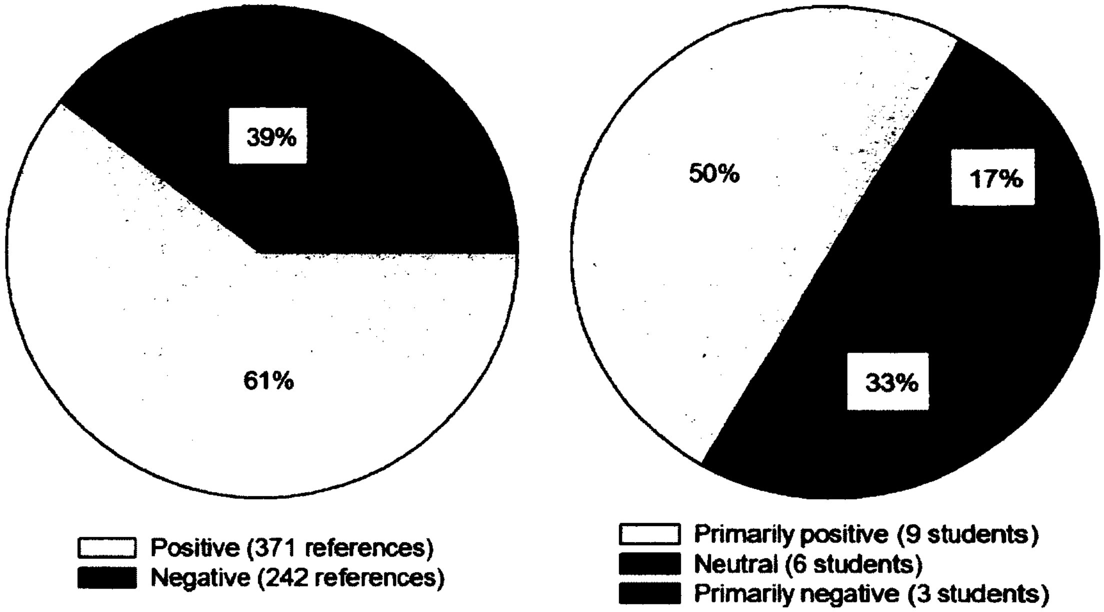


Figure A4.2. Total negative and positive references made by interviewed students (left) and number of students classified as exhibiting a primarily negative, neutral, or positive attitude toward the course (right).

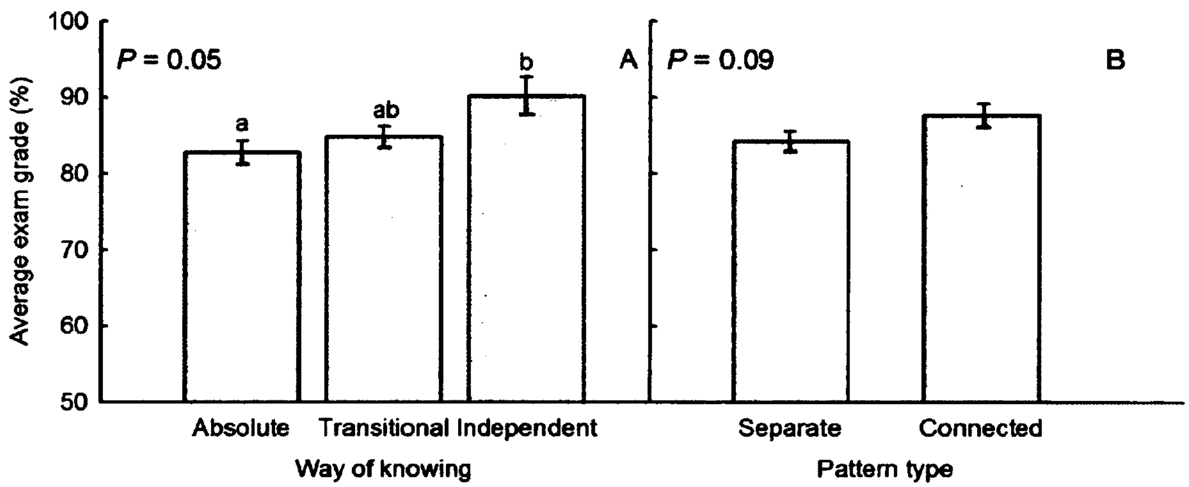


Figure A4.3. The influence of student way of knowing (A) and pattern type (B) on exam performance; N = 49.

Additional Aspects of Studio Soils that Stood Out

Here I describe four additional aspects of the studio structure that could potentially be important components of the studio experience but were not as fully supported as the main categories described in Chapter 4 and the narrative above.

Having two instructors

Four students spoke about the issue of having two instructors teaching at the same time in different rooms. Ingrid focused on students having different learning styles and being afraid she was missing something (like a funny gesture) that would help her remember the information: "I wonder 'Is she doing the same thing in there as we are in here?' because that bothers me because people learn differently...so that's a difficult component too." The other three focused on the different teaching styles of the instructors and how it was difficult getting used to going back and forth between the two styles. For example, Celia said "I don't mind having different people it was just hard 'cause I tried to get used to one person's teaching style and then it'd be switched the next day, and it just kinda gets confusing." An additional student also spoke about the different teaching styles, but unlike Celia, Julie felt that being exposed to more than one teaching style made class more interesting.

These four students felt more anxious at the beginning of the semester but these feelings seemed to have diminished by their exit interview. For example, in her exit interview Ingrid said: "I thought you guys did a really good job with the class because it it's difficult that there were two different...rooms and that's a hard thing to do and I thought that I wouldn't- --it's not that I didn't notice, but it was such a smooth transition all around that it was- --it was good."

Covered less content

Three students' felt that not enough content was covered. For example, Stephen said: "I actually would have liked to maybe even have learned more. I know that we didn't really go into the book too much, but I wouldn't have minded maybe doing another whole unit on something else." Amelia also felt that the last unit in particular "didn't really have as much content, or readings and stuff like that, so I feel like I really didn't get a ton out of this last unit." However, two other students felt that even though they learned less (quantitatively) they actually understood more. For example, Blake said: "I mean obviously there was less lecturing so it was less information I feel like, but it was more like you guys did less information and made sure that it got understood, which was effective, and I definitely think it helped me learn overall." Julie felt similarly: "I really liked how she just focused on what she thought we'd need to know and kind of left out things that were like way beyond that...so definitely I liked the focusing on certain things, and really learn about it, than kind of just like cramming it all in just so we have it on our transcripts."

Busy Work

Four students felt like some of the in class activities were more "busy work" than useful learning opportunities. For example, Zach said: "I do remember there [were] about three or four that I remember specifically going "Why? What is this?" Especially some of the ones at the beginning, they're kind of really just- --I feel like what you'd give to middle schoolers, they're so simple, it's just to see if you have a working brain." Owen also felt frustrated by what he considered to be busy work: "When you give me these like, little busy work things, I just- --okay, yeah, I'll answer the question, but it ticks me off and I feel like I'm wasting time." Stephen did not express the same level of frustration as Zach and Owen but he still noted: "When she made it a point to say that 'This isn't busy work' that's kind of a tip off that it might be busy work, like, I kind of felt that some of the stuff that we were doing, at least in Unit Four, was kind of busy work."

Requires more effort

Two students talked about how the course required more effort than they wanted to put into it sometimes. Elena explained that she was just not always in the mood to put in the required effort:

> Sometimes you're just like not in the mood to like- --yeah that was the only hard part, I mean lectures are good and they also are kind of a pain, but with the group work there was just sometimes when you just weren't in the mood to fill out a worksheet or think about it, whereas like, just taking notes seemed easier and more appealing at the time, just 'cause, I don't know, for two hours, or like right before lunch or something, I was just like "what?" I wasn't in the mood to actually put in the effort to fill out a worksheet {laughs}.

Zach actually said that a hands-on approach helped him learn, but thought that the class required too much work:

> I just think the class might be a little ambitious...If you had twice the information in the class as there is now, I'm sure we'd learn the information better, if we were forced to do even more work, but...there really does seem to be a superfluous amount of work....I mean we had to do at least a handout- --I'd say like the average was like one point five- --in class, then it'd be one or two due for after class on top of reading quizzes to do online....I don't know how significant any of that really is, but that's kinda my first thought, is that there's really a lot of work.

The extra effort combined with Zach's preference for policy classes (he was only taking Studio Soils because it was required), meant Zach would have liked the relaxing atmosphere of a lecture better: "I'm not trying to fully take the course, I'm trying to just get my background out of the course...so I would've probably liked the lecture style. And there woulda been less work, yeah, there woulda been less, like, doing things. I could just sit there and relax, probably get a coffee – that helps me relax."

Additional factors that may inform students' experiences

Here I describe three other factors that may inform students' experiences: prior experiences, perceived learning style, and identifying as a non-traditional student.

Prior experiences

All 20 students described prior experiences that influenced their experiences in Studio Soils. When students spoke of prior experiences they typically were referring to experiences that differed from the studio structure as a whole, though they often made connections to prior experiences that were similar to an aspect of the studio course (Appendix Figure A4.4). Eighteen students (90%) felt that some aspects of the studio structure were better than their prior experiences. In particular, 12 students (60%) felt that the studio structure removed the disconnect between lecture and lab. Six students (30%) also felt that the learning community was more positive (meeting new people, approachability of instructors, being comfortable) than prior experiences. Six students (30%) also contrasted the emphasis on in-class group work to prior negative experiences working in groups on out-of-class projects; six students also (30%) contrasted the mini-lectures to their prior experiences sitting through long lectures. However, eight students (40%) referenced prior experiences that they preferred to the studio-style, including classes that had extended lab periods (20% of students), more lecture (15% of students), or more one-on-one instructor time (10% of students). For two students (10%) the unfamiliarity of the course structure in comparison to their prior experiences caused anxiety about what they were expected to do (see the narrative of students' experiences in Appendix 4 for a more detailed description of the studio structure as a new experience).

Only one student spoke of an experience in a similar structure (at a Montessori high school), but most students (95%) made connections to prior experiences that were similar to an aspect of the studio structure. References to similar prior experiences that were positive (80% of students) tended to focus on the lab portions of lecture-based courses, either in relation to hands-on and field work (45% of students) or in relation to positive experiences working with peers during labs (50% of students). Ten students (50%) also referenced negative experiences that were similar to their experiences in the studio course; these tended to focus on negative experiences working with peers during labs (35% of students) or class discussions during the lecture portion of lecture-based courses (15% of students).

Perceived learning style

Throughout the initial and exit interviews several students referred to their style of learning. The six students who identified as "visual" and/or "hands-on" learners generally spoke more favorably about the studio structure. For example, in her initial interview Ingrid explained: "I like the idea of this class right now, being a studio set-up, because I've always learned better, like hands-on." During her exit interview Ingrid spoke favorably about multiple aspects of Studio Soils, including learning and doing at the same time, being more engaged, working with peers, and feeling like the class was a "close-knit" community. She also elaborated more on how group work matched her learning style and therefore helped her learn:

> I liked that we were actually doing work in the classroom...talking about it in the group. Everybody has their own way of viewing it, so that's helpful for someone like me because I definitely need like, visuals, or like a creative, like way to remember it, and...it definitely helped me grasp the concepts that went behind the material we were doing.

Julie also enjoyed multiple aspects of the course and described how Studio Soils was the first class she had taken that really helped her learn:

> Whenever we had to answer questions, like today in class we had to answer questions together and like talk about it, I think just having time to talk about it instead of like a teacher standing up there asking questions and...whoever knows the most is like {laughing} answering the question. So we got to think about a question, talk about it, then write it down, and those kinda repetitive steps are my kind of learning style, so, there was a lot of repetition in this class I think, which was good.

On the other hand, two students identified lecture-based as their style of learning. Jake, who felt that the class suffered due to time constraints and thought that working in groups hindered his learning, said: "I really like that format of just lecture. Someone just talks to you for an hour and you take notes, it- --I just honestly think that with alternative education- --I've just been doing it for so long that way, it's just harder to break the mold." When asked what part of Studio Soils was most helpful to her learning, Maddie also described lecture-based learning as more in line with her learning style: "I think the majority of it was the mini-lecture material, which I would have preferred more of because it's helpful. I like lecture-based stuff with notes and more of that than filling out worksheets but that's just my weird learning style." In contrast to Jake, Maddie did not have a lot of negative experiences, but neither did she describe her experiences in Studio Soils as positive: "it wasn't like horrible, it wasn't bad, it was just neutral, middle, with a slight positive- --neutral plus."

<u>Identifying as a non-traditional student</u>

While I did not have enough non-traditional students to completely support the idea that identifying as a non-traditional student can affect how students experience a class, two students did frequently describe their experiences in the context of being a non-traditional or transfer student throughout the initial and exit interviews. For example, Stephen spoke about family and his prior career when explaining his motivation for entering the Environmental Conservation and Sustainability program, and as described above, he appreciated working with peers because he was a commuter who was not as involved on campus as other students. He also talked about having to re-learn how to study:

> I guess maybe I'll find this out after the next exam, but I have kind of learned what to look for, as far as exams go. You know when I first came to school, I hadn't been in school for [several] years so I didn't know what to study, or how to study, or anything. So, you kinda pick up on these things, especially after the first exam, 'cause then you see what the professor was focused on, and what parts of the book you should study more, so that's really helped me out {laughs}, just to learn what they key in on.

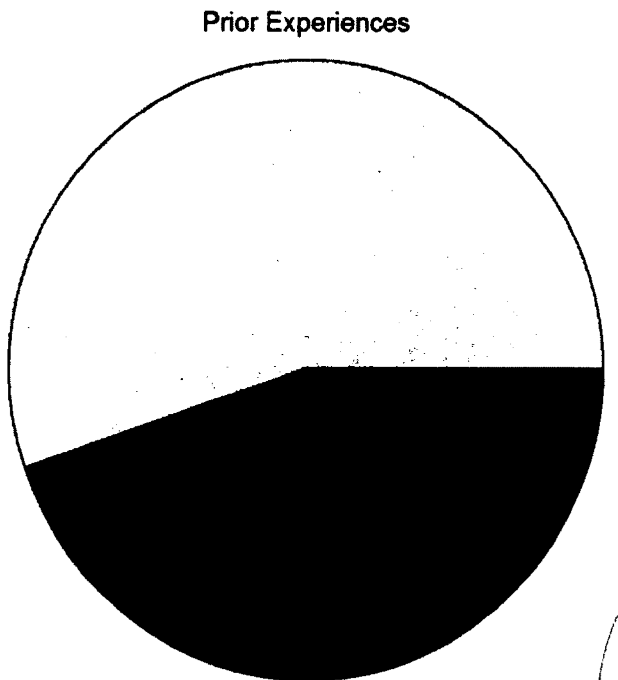
Philip also spoke frequently about being a transfer student and being non-traditional:

> It's good to be like where I'm at as a transfer student because a lot of the classes I'm taking here are for people who are new to the program as well, so we all kind of have the same questions, even though I'm a little older than the majority of my peers, it's kind of a- --makes it a bit interesting at times, but I'd say more or less it's been a pretty good experience.

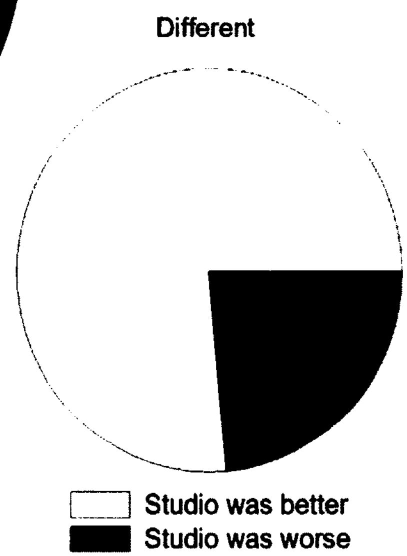
He also brought up being older than other students when relating a story about seeing another student falling asleep during a mini-lecture in Studio Soils:

> I saw somebody- --I almost started to laugh, it was like the second unit and they're sitting over there in their chair and they're like {does the head nodding motion of falling asleep sitting up} and I was like "Dude, come on, really?!" Oh man. I'm sure that happens a lot. Maybe it's just because I'm a little older and I think differently than that.

In addition, Philip had potential insight into other transfer students when he talked about the potential benefit of having a separate workshop on report writing: "The reason I say that is because I think maybe in certain cases where transfer students or other folks get in there, they may never have written one before, so I don't know if like a short workshop or something like that would be beneficial."



Prior experiences	# References (% of total)	# Students (% of total)
Different from studio	**68 (55)**	**18 (90)**
Studio was better	52 (42)	16 (80)
Studio was worse	16 (13)	8 (40)
[redacted]		
Positive experience	40 (33)	16 (80)
Negative experience	15 (12)	11 (55)



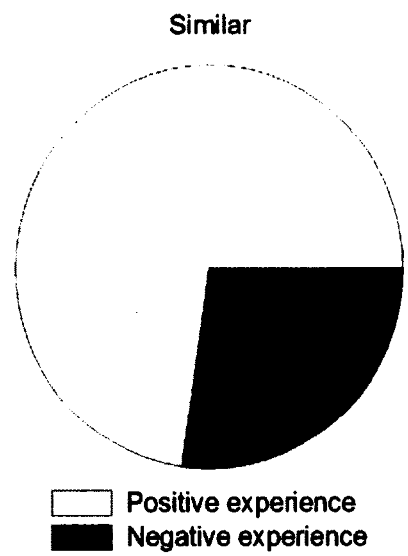


Figure A4.4. Main categories and subcategories of students' prior experiences in relation to their experiences in Studio Soils.

APPENDIX 5: INSTRUMENTS USED

The Measure of Epistemological Reflection can be found in Baxter Magolda (1992). With the exception of the 2009 pre/post-test, which was written by Serita D. Frey, all other instruments included here were written by me. The demographic questionnaire included below is the one filled out by the students in the 2011 cohort; the section of the questionnaire asking students to provide their information if they were interested in participating in interviews was deleted from the questionnaire sent to students who had taken the course in 2009 and 2010.

Demographic Questionnaire

Name (first and last) ____

Gender _________ Age ____ Major ______________ Current GPA _____

Class rank: ___freshman ___sophomore ___junior ___senior

What is your father's highest level of education?
Primary school High school 2-year college 4-year college graduate school

What is your mother's highest level of education?
Primary school High school 2-year college 4-year college graduate school

What is your father's current employment status?
Employed Stay-at-home dad Student Retired Unemployed Deceased

What is your mother's current employment status?
Employed Stay-at-home mom Student Retired Unemployed Deceased

What is your parents' combined net annual income?
$20,000 or less $20,001 - $50,000 $50,001-$100,000 More than $100,000 Don't know

My name is Sarah Andrews and I am a 5th year PhD student at the University of New Hampshire in the Natural Resources and Earth System Sciences program. As part of my research on the experience of Studio Soils I am interested in interviewing students about past experiences in other courses, learning preferences, expectations for Studio Soils, and experiences in Studio Soils. This would involve two 60 minute interviews scheduled at your convenience (one at the beginning of the semester and one at the end). Students who complete both interviews will receive a $10 gift card to the UNH Dairy Bar. If you are interested in being contacted to participate in interviews please fill out the following information:

I am interested in being contacted about participation in interviews.

☐ YES ☐ NO

Email:________________________________

Phone #: ______________________________

I prefer being contacted via: ___email ___phone

If you have any questions about this research please contact Sarah Andrews at sef6@wildcats.unh.edu.
If you have questions about your rights as a research subject you can contact Dr. Julie Simpson in UNH Research Integrity Services, 603-862-2003 or Julie.simpson@unh.edu to discuss them.

Interview Protocols

Initial interview protocol

The purpose of this interview is to get your thoughts on what stands out to you from your experiences as a student, your ideas about your learning as a student, and your expectations for the Studio Soils course. It will be an open-ended interview in order to allow you the opportunity to share your ideas. Feel free to talk about any experiences or ideas that come to mind.

1. What led you to enter your current program (major)?
    a. If a transfer student: What motivated you to transfer schools?
    b. If they changed majors: What motivated you to change your major?
2. What have been your experiences in the program so far?
3. When you think back over your experiences, what stands out the most?
4. What led you to take Studio Soils at this time?
    a. Variant if class was required: Do you think you would have taken Studio Soils if it hadn't been required?
5. What are your goals or expectations for this class?
6. As you think about yourself as a learner, what do you expect from yourself to make learning more effective?
7. What do you expect from professors to help you learn effectively?
8. What kind of experiences have you had with other students?
    a. Additional probe: have your experiences helped or hindered your learning?
9. Is there anything else you would like to share to help me understand your learning experiences so far in your program?

Concluding remarks

Thanks very much for your time and willingness to share your experiences. As you recall, your identity will be kept confidential.

Exit interview protocol

Thanks for continuing with the study! The primary purpose of this interview is to get your thoughts on your experiences in Studio Soils, but please feel free to talk about any learning experiences that stand out to you in other classes as well.

1. What stands out to you from your experience in Studio Soils?
2. How do your experiences in Studio Soils compare to other classes you have taken?
3. If not already discussed: What stands out to you the most from working in groups in Studio Soils? Have these experiences helped or hindered your learning?
4. Of the things we've discussed is there anything that stands out as being most helpful to your learning?
5. Would you change anything about the Studio Soils learning environment you've experienced this semester? If so, what?
6. In the future if you had the opportunity to take a class as a lecture with a separate lab do or as a studio course, would you choose one over the other? Why?
7. Is there anything else you would like to share to help me understand your experiences in Studio Soils or other classes in your program?

Concluding remarks

Thanks very much for your time and willingness to share your experiences. As you recall, your identity will be kept confidential.

Pre-, Post-, and Post-Course Tests

The 2009 pre- and post-test

The test below (written by Serita D. Frey) was given on the first day of class; the post-test given on the last day of class was identical to the test below except the post-test did not include the three survey questions at the beginning of the test (major, year, if the course was required for their major). Also note that more writing space was included for each question on the actual tests given to students.

NR 501 Introduction to Soils
Student Survey

Name:

Major:

Year:

Is this a required course for your major? Yes No

How would you define "soil"?

What are the four major constituents/particle types in all soils?

From where does soil come? That is, from what material is it formed?

What factors are important for soil formation?

Soils are formed in layers called horizons. What soil horizons are typically found in most soils?

How long does it take a soil to form? Please give a number:

There is a soil taxonomy. That is, all soils are named just as all known species of plants and animals are named. How many different "species" of soils are there on the planet? Please give a number:

What types of organisms live in soil (list all you can think of)?

How many organisms live in a handful of garden variety soil? Please give a number:

Are there more species of plants, animals, or soil organisms on the planet (circle one)?

What do soils do? That is, what functions do soils play in ecosystems? (List all you can think of)

What is soil organic matter?

Carbon is a basic building block of life. It is present in soils as organic matter, in vegetation as leaves, tree trunks etc., and it is found in the atmosphere as carbon dioxide (a greenhouse gas). Is there more carbon in the world's soils, vegetation, or in the atmosphere (circle one)?

What contributes more carbon to the atmosphere on a yearly basis: decomposition of soil organic matter or fossil fuel combustion (underline one)?

What are some of the most pressing environmental problems related to soils?

<u>The 2010 pre-test</u>

This test was given on the first day of class. It was modified from the pre/post tests given in 2009 to be multiple-choice so that the analysis could be more objective.

NR 501 Studio Soils
Pre-Test

1. Is this a required course for your major?
    a. Yes
    b. No

2. Have you had a general chemistry course at the college level?
    a. Yes
    b. No

Soil Chemistry and Mineralogy

3. What is a cation?
    a. A negatively charged ion
    b. A positively charged ion
    c. An element or molecule without a charge

4. What is pH?
    a. phosphorus
    b. concentration of hydrogen ions
    c. negative logarithm of the hydrogen ion concentration
    d. logarithm of the hydrogen ion concentration

5. What are the correct abbreviations for carbon, nitrogen, phosphorus, and potassium?
    a. Co, Ne, Pu, Pa
    b. C, N, P, K
    c. Ca, Ni, Po, Pt
    d. Cr, Na, Pr, Pm

Soil Fertility

6. What are the major plant nutrients (macronutrients)?
    a. carbon, hydrogen, and oxygen
    b. nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur
    c. iron, manganese, zinc, copper, cobalt, molybdenum, and boron

7. Which of the following could be a problem that would arise from improper application of nitrogen and phosphorus to soil?
    a. Leaching of excess nutrients into ground and/or surface water
    b. Eutrophication
    c. a and b

8. Adding limestone to a soil will:
    a. Lower the pH of the soil
    b. Raise the pH of the soil
    c. Add nitrogen to the soil
    d. Add phosphorus to the soil

9. Which of the following could affect soil fertility results?
    a. Time of year the soil sample was taken
    b. Depth the soil sample was taken from
    c. Position in the landscape
    d. All of the above

Soil Physics

10. Which of the following represent the four major components in all soils?
    a. Air, water, minerals, and organic matter
    b. Minerals, nutrients, plants, and water
    c. Plants, loam, rocks, and water

11. What is density?
    a. Mass per unit volume
    b. Volume per unit mass

12. What are the three main mineral particle size classes?
    a. coarse sand, fine sand, and clay
    b. rocks, pebbles, and sand
    c. sand, silt, and clay
    d. gravel, sand, and loam

13. Which of the following could affect soil temperature?
    a. Soil color
    b. Soil moisture
    c. Surface residue
    d. All of the above

Soil Genesis, Morphology, and Classification

14. Which of the following do you think best defines 'soil'?
    a. A mixture of sand, silt, and clay particles
    b. A mixture of minerals, organic matter, gases, liquids, and living organisms which can support the growth of plants
    c. Rocks that have been broken down into a mixture of sand, silt, and clay which can support the growth of plants

15. What is the term for the material that soil is formed from?
    a. substrate
    b. parent material
    c. rocky material
    d. tilth

16. Soils are formed in layers called horizons. What soil horizons are typically found in most soils?
    a. O, A, B, and C
    b. A, B, C, D, and E
    c. V, W, X, Y, and Z
    d. A, B, C, Y, and Z

17. What are the main factors of soil formation?
    a. vegetation and precipitation
    b. time, topography, biota, parent material, and climate
    c. bedrock, microorganisms, and time

18. All soils are classified (i.e., named) just as all known species of plants and animals are named. Approximately how many different "species" of soils have been classified in the United States?
    a. 1000
    b. 10,000
    c. 20,000
    d. 1,000,000

19. How long does it take a soil to form?
    a. decades
    b. centuries
    c. millennia
    d. decades to hundreds of millennia

Soil Biology and Biochemistry

20. If a soil has 10% carbon and 0.5% nitrogen, what is the carbon to nitrogen ratio?
    a. 0.05
    b. 5
    c. 10.5
    d. 20

21. What is soil organic matter?
    a. living organisms
    b. dead roots and other recognizable plant residues
    c. complex organic substances no longer identifiable as residues
    d. all of the above

22. What is decomposition?
    a. The transfer of heat through a gas or solution because of molecular movement
    b. The chemical breakdown of compounds into simpler compounds, often accomplished with the aid of microorganisms
    c. The conversion of an element from the inorganic form to the organic form
    d. Physical or mechanical breakdown or separation of a substance into its component parts

23. What is the rhizosphere?
    a. Plant roots
    b. The portion of soil close to plant roots where microbes are influenced by the roots
    c. Swollen growths on plant roots
    d. The pool of bacteria that can colonize roots

24. Approximately how many organisms live in a handful of soil?
    a. 100's
    b. 1,000's
    c. 1,000,000's
    d. 1,000,000,000's

25. Which of the following is a true statement about soil biodiversity:
    a. Soils contain about the same number of species as there are species of plants.
    b. Soils contain more total species than the number of plant and animal species combined.
    c. Soils are not very diverse.

26. Carbon is a basic building block of life. It is present in soils as organic matter, in vegetation as leaves, tree trunks etc., and in the atmosphere as carbon dioxide (a greenhouse gas). Which of the following statements about carbon is true:
    a. Soils contain two times the amount of carbon as that found in vegetation and the atmosphere combined.
    b. The majority of carbon in the terrestrial biosphere is stored in vegetation (e.g., tree biomass in temperate and tropical rain forests).
    c. Soils contain about half as much carbon as that found in vegetation and the atmosphere.

Land Use Management

27. What contributes more carbon to the atmosphere on a yearly basis:
    a. decomposition of soil organic matter
    b. fossil fuel combustion

28. What is eutrophication?
    a. Nutrient enrichment of waters that stimulates the growth of aquatic organisms and leads to oxygen deficiency in the water
    b. The combined loss of water from a given area during a specified period of time
    c. A build-up within an organism of specific compounds due to biological processes
    d. Peeling away of layers of a rock from the surface inward due to expansion and contraction

The 2010 Biosphere pre-test

This test was given the day the Biosphere Unit started. The purpose of this test was to assess knowledge not covered in the basic pre-test given on the first day of class; additionally, effort was made to improve the format of the questions so that every question had the same number of choices (four) and no question included 'all of the above' as one of the choices.

NR 501 Studio Soils
Unit 2 (Biosphere) pre-test

1. Soils that form under coniferous vegetation, usually in moist and cold environments, are termed:
    a. Alfisols
    b. Gelisols
    c. Histosols
    d. Spodosols

2. Intermediately weathered soils that form under deciduous forests are termed:
    a. Alfisols
    b. Gelisols
    c. Spodosols
    d. Histosols

3. Mollisols are soils that:
    a. Occur mostly on course-textured, acid parent materials
    b. Have an accumulation of calcium rich organic matter in their surface horizon
    c. Form in hot climates with nearly year-round moist conditions
    d. Consist of one or more thick layers of organic soil material

4. The process of cation exchange is when:
    a. Negatively charged ions exchange between the soil solution and the rhizosphere
    b. Negatively charged ions exchange between the soil solution and the surface of soil colloids
    c. Positively charged ions exchange between the soil solution and the rhizosphere
    d. Positively charged ions exchange between the soil solution and the surface of soil colloids

5. In general, increases in soil organic matter would cause the soil's cation exchange capacity to:
    a. Fluctuate
    b. Decrease
    c. Increase
    d. Stay the same

6. In general, the cation exchange capacity of a soil with high clay content would __________ a sandier soil.
    a. Fluctuate more than
    b. Be lower than
    c. Be higher than
    d. Be the same as

7. Which of the following processes cause soil acidity?
    a. Atmospheric deposition of H_2SO_4 and HNO_3 and accumulation of organic matter
    b. Atmospheric deposition of Ca and Mg and input of bicarbonates and carbonates
    c. Atmospheric deposition of H_2SO_4 and HNO_3 and input of bicarbonates and carbonates
    d. Atmospheric deposition of Ca and Mg and accumulation of organic matter

8. The pool of active acidity in a soil is:
    a. H^+ in the soil solution readily measured with a pH electrode
    b. H^+ and Al^{3+} that are easily exchangeable by other cations in a salt solution
    c. H^+ and Al^{3+} that can be neutralized by limestone but aren't exchangeable by other cations in a salt solution
    d. The sum of the above three types of acidity

9. A soil with a pH of 7.5 would have <u>higher</u> availability of ________________ than a soil with a pH of 4.5
    a. manganese, zinc, calcium, and magnesium
    b. nitrogen, phosphorus, calcium and magnesium
    c. aluminum, iron, manganese and zinc
    d. aluminum, iron, nitrogen, and phosphorus

10. A soil with a pH of 7.5 would have <u>lower</u> availability of ________________ than a soil with a pH of 4.5
    a. manganese, zinc, calcium, and magnesium
    b. nitrogen, phosphorus, calcium, and magnesium
    c. aluminum, iron, manganese, and zinc
    d. aluminum, iron, nitrogen, and phosphorus

11. The arrangement of sand, silt, clay, and organic particles into secondary units called aggregates is the definition for soil __________:
    a. texture
    b. separates
    c. association
    d. structure

12. In general, the formation of soil aggregates is enhanced by
    a. long periods of tillage, plant roots, organic matter, clay, and the activity of soil organisms
    b. long periods of tillage, plant roots, organic matter, sand, and the activity of soil organisms
    c. low tillage, plant roots, organic matter, clay, and the activity of soil organisms
    d. low tillage, plant roots, organic matter, sand, and the activity of soil organisms

13. In general, organic material with a ______________ would be the easiest for most soil microbes to degrade
    a. low C:N ratio and high lignin content
    b. low C:N ratio and low lignin content
    c. high C:N ratio and high lignin content
    d. high C:N ratio and low lignin content

14. A mycorrhiza is a:
    a. parasitic association of bacteria with plant roots
    b. mutualistic association of bacteria with plant roots
    c. parasitic association of fungi with plant roots
    d. mutualistic association of fungi with plant roots

15. Earthworm activity can:
    a. Decrease soil fertility, decrease aggregate stability, remove surface residues, and decrease the flow of potential pollutants into the groundwater
    b. Enhance soil fertility, enhance aggregate stability, remove surface residues, and increase the flow of potential pollutants into the groundwater.
    c. Enhance soil fertility, enhance aggregate stability, add surface residues, and increase the flow of potential pollutants into the groundwater
    d. Enhance soil fertility, decrease aggregate stability, add surface residues, and increase the flow of potential pollutants into the groundwater

The 2010 post-test

This test was given on the last day of class. The basic post-test given on the first day of class and the Biosphere pre-test were combined into a single post-test; however, only questions from the basic pre-test that had four possible choices and that did not include 'all of the above' as one of the choices were included on the post-test.

NR 501 Studio Soils
2010 Post-Test

1. A cation is _______.
   a. a negatively charged ion
   b. a positively charged ion
   c. an element or molecule without a charge
   d. none of the above

2. Soil pH is defined as the ___________.
   a. phosphorus concentration in the soil solution
   b. amount of hydrogen ions associated with soil colloids
   c. the hydrogen ion (H^+) concentration of the soil solution
   d. the hydroxide (OH^-) concentration in the soil solution

3. The major plant nutrients (macronutrients) are _____________.
   a. carbon, hydrogen, and oxygen
   b. nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur
   c. iron, manganese, zinc, copper, cobalt, molybdenum, and boron
   d. nitrogen, phosphorus, potassium, iron, manganese, copper

4. Adding limestone to a soil will ______________.
   a. Lower the pH of the soil
   b. Raise the pH of the soil
   c. Add nitrogen to the soil
   d. Add phosphorus to the soil

5. What is the term for the material that soil is formed from?
   a. substrate
   b. parent material
   c. rocky material
   d. tilth

6. All soils are classified (i.e., named) just as all known species of plants and animals are named. Approximately how many different "species" of soils have been classified in the United States?
   a. 1000
   b. 10,000
   c. 20,000
   d. 1,000,000

7. Soils that form under coniferous vegetation, usually in moist and cold environments, are termed:
   a. Alfisols
   b. Gelisols
   c. Histosols
   d. Spodosols

8. Intermediately weathered soils that form under deciduous forests are termed:
   a. Alfisols
   b. Gelisols
   c. Spodosols
   d. Histosols

9. How long does it take a soil to form?
   a. decades
   b. centuries
   c. millennia
   d. decades to hundreds of millennia

10. The process of cation exchange is when:
   a. Negatively charged ions exchange between the soil solution and the surface of soil colloids
   b. Negatively charged ions exchange between the soil solution and the rhizosphere
   c. Positively charged ions exchange between the soil solution and the rhizosphere
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    c. aluminum, iron, manganese and zinc
    d. aluminum, iron, nitrogen, and phosphorus

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    a. manganese, zinc, calcium, and magnesium
    b. nitrogen, phosphorus, calcium, and magnesium
    c. aluminum, iron, manganese, and zinc
    d. aluminum, iron, nitrogen, and phosphorus

17. If a soil has 10% carbon and 0.5% nitrogen, what is the carbon to nitrogen ratio?
    a. 0.05
    b. 5
    c. 10.5
    d. 20

18. In general, organic material with a _____________ would be the easiest for most soil microbes to degrade
    a. low C:N ratio and high lignin content
    b. low C:N ratio and low lignin content
    c. high C:N ratio and high lignin content
    d. high C:N ratio and low lignin content

19. What is decomposition?
    a. The transfer of heat through a gas or solution because of molecular movement
    b. The chemical breakdown of compounds into simpler compounds, often accomplished with the aid of microorganisms
    c. The conversion of an element from the inorganic form to the organic form
    d. Physical or mechanical breakdown or separation of a substance into its component parts

20. Approximately how many organisms live in a handful of soil?
    a. 100's
    b. 1,000's
    c. 1,000,000's
    d. 1,000,000,000's

21. A mycorrhiza is a:
    a. parasitic association of bacteria with plant roots
    b. mutualistic association of bacteria with plant roots
    c. parasitic association of fungi with plant roots
    d. mutualistic association of fungi with plant roots

22. Earthworm activity can:
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    c. Enhance soil fertility, enhance aggregate stability, add surface residues, and increase the flow of potential pollutants into the groundwater
    d. Enhance soil fertility, decrease aggregate stability, add surface residues, and increase the flow of potential pollutants into the groundwater

23. Carbon is a basic building block of life. It is present in soils as organic matter, in vegetation as leaves, tree trunks etc., and in the atmosphere as carbon dioxide (a greenhouse gas). Which of the following statements about carbon is true:
    a. Soils contain two times the amount of carbon as that found in vegetation and the atmosphere combined.
    b. The majority of carbon in the terrestrial biosphere is stored in vegetation (e.g., tree biomass in temperate and tropical rain forests).
    c. Soils contain about half as much carbon as that found in vegetation and the atmosphere.
    d. None of the above

24. What contributes more carbon to the atmosphere on a yearly basis:
    a. decomposition of soil organic matter
    b. fossil fuel combustion
    c. photosynthesis
    d. methanogenesis

25. The arrangement of sand, silt, clay, and organic particles into secondary units called aggregates is the definition for soil __________:
    a. texture
    b. separates
    c. association
    d. structure

26. In general, the formation of soil aggregates is enhanced by
    a. long periods of tillage, plant roots, organic matter, clay, and the activity of soil organisms
    b. long periods of tillage, plant roots, organic matter, sand, and the activity of soil organisms
    c. low tillage, plant roots, organic matter, clay, and the activity of soil organisms
    d. low tillage, plant roots, organic matter, sand, and the activity of soil organisms

The 2011 Lithosphere pre-test

This test was given on the first day of class and includes four new questions in addition to the questions from the 2010 post-test related to the lithosphere. Each multiple-choice question also now includes a space for students to indicate their confidence in their choice.

NR 501 Studio Soils
Unit 1 pre-test: Soils and the Lithosphere

Name:______________________________________ **Date:**______________

1. Is this a required course for your major?
    a. Yes
    b. No

2. Have you had a general chemistry course at the college level?
    a. Yes
    b. No

For each question below please circle the letter of the best response. Please also indicate your confidence in your choice to the right of each question by checking the appropriate level.

1. All soils are classified (i.e., named) just as all known species of plants and animals are named. Approximately how many different "species" of soils have been classified in the United States?
    a. 1000
    b. 10,000
    c. 20,000
    d. 1,000,000

    ___I know this
    ___I'm pretty sure
    ___I guessed

2. How long does it take a soil to form?
    a. decades
    b. centuries
    c. millennia
    d. decades to hundreds of millennia

    ___I know this
    ___I'm pretty sure
    ___I guessed

3. What are the main factors of soil formation?
    a. vegetation, precipitation, location, temperature, and topography
    b. time, topography, biota, parent material, and climate
    c. bedrock, vegetation, microorganisms, time, and precipitation
    d. parent material, location, biota, precipitation, and temperature

    ___I know this
    ___I'm pretty sure
    ___I guessed

4. Which of the following parent materials are formed in place?
   a. bedrock, and peat
   b. peat and colluvium
   c. colluvium and loess
   d. loess and bedrock

___I know this
___I'm pretty sure
___I guessed

5. What are the three main mineral particle size classes of soil?
   a. coarse sand, fine sand, and clay
   b. rocks, pebbles, and sand
   c. sand, silt, and clay
   d. gravel, sand, and loam

___I know this
___I'm pretty sure
___I guessed

6. You are out scouting land for a community garden and you've found four sites that are in good locations. You've determined the soil texture at each site and found that Site 1 has a sandy soil, Site 2 has a loamy sand soil, Site 3 has a silt loam soil, and Site 4 has a silty clay soil. Based on soil texture, which site do you think would be most appropriate for your community garden?
   a. Site 1   b. Site 2   c. Site 3   d. Site 4

___I know this
___I'm pretty sure
___I guessed

7. You're out walking your dog in College Woods and she runs off trail to investigate something. When you follow her you find that someone has dug a pit in the ground. Curious to see what the soil looks like beneath your feet you step into the pit and notice several layers distinguishable by their different colors. The top most layer is very black in color. The next layer is very dark brown. Beneath that is a thin band of white soil. The final layer that you can see is reddish brown in color. Based on these colors, which soil horizons do you think are present in this soil?
   a. A, B, C, and D   b. A, E, C, and R
   c. O, A, E, and B   d. O, A, B, and C

___I know this
___I'm pretty sure
___I guessed

8. After looking more closely you see that there might be another layer in the soil that is just starting at the bottom of the pit. This soil appears to be more yellowish brown in color. What elements do you think contribute to the reddish and yellowish colors in the final two layers of the soil?
   a. carbon and nitrogen   b. nitrogen and phosphorus
   c. phosphorus and iron   d. iron and aluminum

___I know this
___I'm pretty sure
___I guessed

9. You're visiting a friend in Texas and are having an iced tea in his back yard. Your friend tells you he's interested in starting a garden but his soil is pure clay. He takes you over to an area of the yard where the grass is thin to show you the soil and you notice that there are some pretty deep cracks in the dry soil. Based on this information, the soil is most likely from which order?
   a. Entisol   b. Inceptisol   c. Vertisol   d. Andisol

___I know this
___I'm pretty sure
___I guessed

The 2011 Biosphere Pre-Test

This test was given at the beginning of the first class of the Biosphere Unit and includes one new question in addition to questions from the 2010 post-test related to the biosphere.

NR 501 Studio Soils
Unit 2 pre-test: Soils and the Biosphere

Name:________________________________ **Date:**______________

For each question below please circle the letter of the best response. Please also indicate your confidence in your choice to the right of each question by checking the appropriate level.

1. Carbon is a basic building block of life. It is present in soils as organic matter, in vegetation as leaves, tree trunks etc., and in the atmosphere as carbon dioxide (a greenhouse gas). Which of the following statements about carbon is true:
   a. The majority of carbon in the terrestrial biosphere is stored in vegetation (e.g., tree biomass in temperate and tropical rain forests)
   b. Soils contain about half as much carbon as that found in vegetation and the atmosphere
   c. Soils, vegetation, and the atmosphere all contain about equal amounts of carbon
   d. Soils contain two times the amount of carbon as that found in vegetation and the atmosphere combined

   ___I know this
   ___I'm pretty sure
   ___I guessed

2. Approximately how many organisms live in a handful of soil?
   a. 100's
   b. 1,000's
   c. 1,000,000's
   d. 1,000,000,000's

   ___I know this
   ___I'm pretty sure
   ___I guessed

3. A mycorrhiza is a:
   a. parasitic association of bacteria with plant roots
   b. mutualistic association of bacteria with plant roots
   c. parasitic association of fungi with plant roots
   d. mutualistic association of fungi with plant roots

   ___I know this
   ___I'm pretty sure
   ___I guessed

4. The arrangement of sand, silt, clay, and organic particles into secondary units called aggregates is the definition for soil __________:
   a. texture
   b. separates
   c. association
   d. structure

   ___I know this
   ___I'm pretty sure
   ___I guessed

5. In general, the formation of soil aggregates is enhanced by
   a. high tillage, plant roots, the activity of soil organisms, organic matter, and clay
   b. high tillage, plant roots, the activity of soil organisms, organic matter, and sand
   c. low tillage, plant roots, the activity of soil organisms, organic matter, and clay
   d. low tillage, plant roots, the activity of soil organisms, organic matter, and sand

___I know this
___I'm pretty sure
___I guessed

6. In general, organic material with which of the following characteristics would be easier for most soil microbes to degrade?
   a. low C:N ratio and high lignin content
   b. low C:N ratio and low lignin content
   c. high C:N ratio and high lignin content
   d. high C:N ratio and low lignin content

___I know this
___I'm pretty sure
___I guessed

7. The process of cation exchange is when:
   a. Negatively charged ions exchange between the soil solution and the rhizosphere
   b. Negatively charged ions exchange between the soil solution and the surface of soil colloids
   c. Positively charged ions exchange between the soil solution and the rhizosphere
   d. Positively charged ions exchange between the soil solution and the surface of soil colloids

___I know this
___I'm pretty sure
___I guessed

8. In general, increases in soil organic matter would cause a soil's cation exchange capacity to:
   a. Fluctuate
   b. Decrease
   c. Increase
   d. Stay the same

___I know this
___I'm pretty sure
___I guessed

9. Which of the following processes cause soil acidity?
   a. Atmospheric deposition of H_2SO_4 and HNO_3 and accumulation of organic matter
   b. Atmospheric deposition of Ca and Mg and input of bicarbonates and carbonates
   c. Atmospheric deposition of H_2SO_4 and HNO_3 and input of bicarbonates and carbonates
   d. Atmospheric deposition of Ca and Mg and accumulation of organic matter

___I know this
___I'm pretty sure
___I guessed

10. You're visiting a friend who just started gardening. She recently got back soil test results from her new raised bed and found out that the soil has really low concentrations of the following plant nutrients: nitrogen, phosphorus, calcium, and magnesium. Knowing that you have some background in soils she asks you what you think could cause the low concentrations and what she could do to help increase the concentration of those nutrients. Of the following, which would be the best response?
    a. The pH of the soil could be too high and she could add pine needles or a sulfur compound to the soil to lower it
    b. The pH of the soil could be too high and she could add agricultural lime to lower it
    c. The pH of the soil could be too low and she could add agricultural lime to raise it
    d. The pH of the soil could be too low and she could add pine needles or a sulfur compound to raise it

___I know this
___I'm pretty sure
___I guessed

The 2011 Atmosphere pre-test

This test was given at the beginning of the first class of the Atmosphere Unit; none of the questions on this test were included on the 2010 post-test.

NR 501 Studio Soils
Fall 2011
Unit 4 pre-test: Soils and the Atmosphere

Name:____ **Date:**_______________

For each question below please circle the letter of the best response. Please also indicate your confidence in your choice to the right of each question by checking the appropriate level.

1. Desertification refers to the
    a. formation of deserts in temperate ecosystems
    b. degradation of formerly productive land in arid ecosystems
    c. expansion of existing deserts
    d. all of the above

    ___I know this
    ___I'm pretty sure
    ___I guessed

2. Salinization is the
    a. removal of precipitates from soils
    b. accumulation of precipitates in soils
    c. removal of soluble salts from soils
    d. accumulation of soluble salts in soils

    ___I know this
    ___I'm pretty sure
    ___I guessed

3. Salinization is a soil problem that typically occurs in areas that have:
    a. low precipitation and high evaporation
    b. high precipitation and high evaporation
    c. high precipitation and low evaporation
    d. low precipitation and low evaporation

    ___I know this
    ___I'm pretty sure
    ___I guessed

4. What is a potential consequence of irrigation in arid lands?
    a. desertification
    b. salinization
    c. both a and b
    d. neither a nor b

    ___I know this
    ___I'm pretty sure
    ___I guessed

5. The process of denitrification is when:
    a. organic nitrogen is converted to inorganic nitrogen
    b. inorganic nitrogen is converted to organic nitrogen
    c. ammonium nitrogen is converted to nitrate nitrogen
    d. nitrate nitrogen is converted to nitrogen gas

    ___I know this
    ___I'm pretty sure
    ___I guessed

6. Soils play a role in regulating which of the following greenhouse gases?
    a. carbon dioxide and methane
    b. methane and nitrous oxide
    c. carbon dioxide and nitrous oxide
    d. carbon dioxide, methane, and nitrous oxide

___I know this
___I'm pretty sure
___I guessed

7. Which of the following processes are mediated by anaerobic bacteria in the soil?
    a. methanotrophy
    b. ammonification
    c. nitrification
    d. denitrification

___I know this
___I'm pretty sure
___I guessed

8. You are a soil scientist traveling around the globe measuring soil respiration. As you move from regions that have low mean annual temperatures and precipitation to regions that have high mean annual temperatures and precipitation you are expecting to find that in general soil respiration will:
    a. decrease
    b. increase
    c. stay the same
    d. fluctuate

___I know this
___I'm pretty sure
___I guessed

9. Under which of the following vegetation type would you expect to see the highest soil respiration?
    a. boreal forest
    b. tundra
    c. tropical moist forest
    d. tropical grassland

___I know this
___I'm pretty sure
___I guessed

10. Under which of the following vegetation type would you expect to see the lowest soil respiration?
    a. boreal forest
    b. tundra
    c. tropical moist forest
    d. tropical grassland

___I know this
___I'm pretty sure
___I guessed

The post-course test and 2011 post-test

This test was sent out to students from all cohorts (2009, 2010, and 2011) to take two years after they completed the course. It is identical to the post-test given on the last day of class in 2011 except that test did not include the survey questions related to subsequent soils-related experiences. Additionally, the order the questions appeared in differed. Five to ten questions were selected from each of the three 2011 unit pre-tests (Lithosphere, Biosphere, Atmosphere). No pre-test was given before the Hydrosphere unit in 2011 and so no hydrosphere-specific questions were included on this test.

NR 501
Two-Year Post-Course Test

Name:____ **Date:**_______________

1. In the time since NR 501 have you taken any other soils courses (at UNH or elsewhere)? If yes, please list them below.

2. In the time since NR 501 have you taken any courses that include soils content (at UNH or elsewhere)? If yes, please list them below and include a brief description of the type of soils information covered.

3. In the time since NR 501 have you had any soils related work experience? If yes, please describe briefly below.

For each question below please circle the letter of the best response. Please also indicate your confidence in your choice to the right of each question by checking the appropriate level.

1. Desertification refers to the
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   a. vegetation, precipitation, location, temperature, and topography
   b. time, topography, biota, parent material, and climate
   c. bedrock, vegetation, microorganisms, time, and precipitation
   d. parent material, location, biota, precipitation, and temperature

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___I guessed

16. In general, the formation of soil aggregates is enhanced by

    a. high tillage, plant roots, the activity of soil organisms, organic matter, and clay
    b. high tillage, plant roots, the activity of soil organisms, organic matter, and sand
    c. low tillage, plant roots, the activity of soil organisms, organic matter, and clay
    d. low tillage, plant roots, the activity of soil organisms, organic matter, and sand

___I know this
___I'm pretty sure
___I guessed

17. In general, increases in soil organic matter would cause a soil's cation exchange capacity to:
    a. Fluctuate
    b. Decrease
    c. Increase
    d. Stay the same

___I know this
___I'm pretty sure
___I guessed

18. You're visiting a friend who just started gardening. She recently got back soil test results from her new raised bed and found out that the soil has really low concentrations of the following plant nutrients: nitrogen, phosphorus, calcium, and magnesium. Knowing that you have some background in soils she asks you what you think could cause the low concentrations and what she could do to help increase the concentration of those nutrients. Of the following, which would be the best response?
    a. The pH of the soil could be too high and she could add pine needles or a sulfur compound to the soil to lower it
    b. The pH of the soil could be too high and she could add agricultural lime to lower it
    c. The pH of the soil could be too low and she could add agricultural lime to raise it
    d. The pH of the soil could be too low and she could add pine needles or a sulfur compound to raise it

___I know this
___I'm pretty sure
___I guessed

19. You're out walking your dog in College Woods and she runs off trail to investigate something. When you follow her you find that someone has dug a pit in the ground. Curious to see what the soil looks like beneath your feet you step into the pit and notice several layers distinguishable by their different colors. The top most layer is very black in color. The next layer is very dark brown. Beneath that is a thin band of white soil. The final layer that you can see is reddish brown in color. Based on these colors, which soil horizons do you think are present in this soil?
    a. A, B, C, and D   b. A, E, C, and R
    c. O, A, E, and B   d. O, A, B, and C

___I know this
___I'm pretty sure
___I guessed

20. After looking more closely you see that there might be another layer in the soil that is just starting at the bottom of the pit. This soil appears to be more yellowish brown in color. What elements do you think contribute to the reddish and yellowish colors in the final two layers of the soil?
    a. carbon and nitrogen
    b. nitrogen and phosphorus
    c. phosphorus and iron
    d. iron and aluminum

___I know this
___I'm pretty sure
___I guessed

APPENDIX 6: INSTITUTIONAL REVIEW BOARD APPROVAL

I initially submitted one proposal to the Institutional Review Board (IRB) for the 2011 cohort only and requested permission (with students' consent) to use students coursework, pre, post, and post-course tests, and a demographic questionnaire for research. Permission was also requested to access students' records, to conduct interviews and to administer the Measure of Epistemological Reflection. The IRB approved this proposal before the start of the fall 2011 semester (IRB #5243). After the initial proposal was approved I submitted a modified proposal requesting permission to change the incentive for the post-course tests. The IRB approved this modified proposal before students were asked to participate in the post-course tests. Both approval letters are included below.

I also submitted a second original proposal to the IRB requesting permission to contact past students (2009 and 2010 cohorts) to take post-course tests and fill out a demographic questionnaire. Permission was also requested to access their records and to use their coursework for research purposes (IRB #5313). The IRB approved this proposal before I contacted any student from 2009 or 2010 to ask them to participate in the research. After this proposal was approved I submitted a modified proposal requesting permission to change the incentive for the two-year post-course tests for students in the 2010 cohort. The IRB approved this modified proposal before students from 2010 were asked to participate in the two-year post-course test. Both approval letters are included below.

University *of* New Hampshire

Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

06-Sep-2011

Andrews, Sarah
Natural Resources and Earth System Science, Rudman
254 Jones Ave
Portsmouth, NH 03801

IRB #: 5243
Study: Integrating Student-Centered Active Learning into an Introductory Soil Science Course: Exploring Relationships Amongst Students' Learning, Perspectives on their Experiences, and their Ways of Knowing
Approval Date: 26-Aug-2011

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Exempt as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 101(b). Approval is granted to conduct your study as described in your protocol.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the attached document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* (This document is also available at http://unh.edu/research/irb-application-resources.) Please read this document carefully before commencing your work involving human subjects.

Upon completion of your study, please complete the enclosed Exempt Study Final Report form and return it to this office along with a report of your findings.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie F. Simpson
Director

cc: File
Frey, Serita

University *of* New Hampshire

Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

07-Mar-2012

Andrews, Sarah
Natural Resources and Earth System Science, Rudman Hall
254 Jones Ave
Portsmouth, NH 03801

IRB #: 5243
Study: Integrating Student-Centered Active Learning into an Introductory Soil Science Course: Exploring Relationships Amongst Students' Learning, Perspectives on their Experiences, and their Ways of Knowing
Study Approval Date: 26-Aug-2011
Modification Approval Date: 29-Feb-2012
Modification: Addition of incentive

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved your modification to this study, as indicated above. Further changes in your study must be submitted to the IRB for review and approval prior to implementation.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* This document is available at http://unh.edu/research/irb-application-resources or from me.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study.

For the IRB,

Julie F. Simpson
Director

cc: File
Frey, Serita

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Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

18-Nov-2011

Andrews, Sarah
Natural Resources and Earth System Science, Rudman
254 Jones Ave
Portsmouth, NH 03801

IRB #: 5313
Study: Student Learning and Retention of Soils Information and Concepts: A Comparison Between a Traditional Lecture Course and its Newly Restructured Student-Centered Active Learning Format
Approval Date: 18-Nov-2011

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Exempt as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 101(b). Approval is granted to conduct your study as described in your protocol.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the attached document, *Responsibilities of Directors of Research Studies Involving Human Subjects*. (This document is also available at http://unh.edu/research/irb-application-resources.) Please read this document carefully before commencing your work involving human subjects.

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For the IRB,

Julie F. Simpson
Director

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07-Mar-2012

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For the IRB,

Julie F. Simpson
Director

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