RESEARCH IN PROTEIN NUTRITION OF LACTATING DAIRY COWS AND ANIMAL AND DAIRY SCIENCES EDUCATION

by

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DEDICATION

To my family and friends

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LIST OF ACRONYMS

AA	Amino acid
ADF	Acid detergent fiber
ADFom	Acid detergent fiber corrected for ash
ADICP	Acid detergent insoluble crude protein
ADSA	American Dairy Science Association
AFIs	Alternative fit indices
ANSC	Animal Sciences
AS	Associate degree
ASAS	American Society of Animal Science
BBCollaborate	Blackboard Collaborate
BCS	Body Condition Score
BIC	Bayesian Information Criterion
BS	Bachelor's degree
BW	Body weight
CA	California
CE	Courses and experiences
CFA	Confirmatory factor analysis
CFI	Comparative fit index
CH4	Methane
CI	Confidence interval
CO2	Carbon dioxide
CP	Crude protein
CTRL	Control
CUREs	Course-based undergraduate research
DBER	Discipline-based education research
DIM	Days in milk
DM	Dry matter
DMI	Dry matter intake
EAA	Essential amino acid
EDTA	Ethylenediaminetetraacetic acid
EE	Ether extract
EPA	Environmental Protection Agency
EVT	Expectancy value theory
FIML	Full Information Maximum Likelihood
FP	Feeding Pattern
FPCM	Fat- and protein-corrected milk
GED	High school diploma or equivalency
GHG	Greenhouse gas

GIS	Geographic information systems
GPA	Grade point average
GRR	Growth rate reliability
HBCU	Historically black colleges and universities
HP	High protein
ICC	Intra-class correlation coefficient
IDF	International Dairy Federation
IFSM	Integrated Farm System Model
II	Individual Interest
IIQ	Individual Interest Questionnaire
IPEDS	Integrated Postsecondary Education Data System
IQR	Inter-quartile range
IU	International Unit
KMO	Kaiser-Meyer-Olkin statistic
LGBTQ	Lesbian, gay, bisexual, transgender, queer, and questioning
LGCM	Latent growth curve model
LMM	Linear mixed model
LO	Learning outcomes
LP	Low protein
MBA	Master's in business administration
MD	Professional degree (MD, JD, DDS, etc.)
MFI	McDonald's non-centrality index
MP	Metabolizable protein
MPY	Milk protein yield
MS	Master's degree
MUN	Milk urea nitrogen
MUNY	Milk urea nitrogen yield
NACTA	North American College Teachers of Agriculture
NASEM	National Academies of Sciences, Engineering, and Medicine
NASS	National Agricultural Statistics Service
NCES	National Center for Educational Statistics
NDF	Neutral detergent fiber
NDFom	Neutral detergent fiber corrected for ash
NDICP	Neutral detergent fiber insoluble crude protein
NEL	Net energy of lactation
NH3	Ammonia
NMPF	National Milk Producers Federation
NO	Nitrogen oxides
NRC	National Research Council
NUE	Nitrogen use efficiency
OECD	Organization for Economic Cooperation and Development

OF	Oscillating feeding pattern
OM	Organic matter
PC	Principal component
PCA	Principal component analysis
PM	Particulate matter
PUN	Plasma urea nitrogen
QR	Quick Response
RDP	Rumen-degradable protein
REML	Restricted maximum likelihood
RMSEA	Root mean square error of approximation
RNA	Ribonucleic acid
RPM	Rotations per minute
SD	Standard deviation
SE	Standard error
SEM	Standard error of the mean
SF	Static feeding
SIQ	Situational interest questionnaire
SRMR	Standardized Root Mean Square Residual
STEM	Science, technology, engineering, and mathematics
TA	Teaching assistant
TAA	Total amino acid
TL	Teaching and learning
TLI	Tucker-Lewis Index
TMR	Total mixed ration
TPI	Teaching Practices Inventory
UCR	Urea clearance rate
UN	Urinary nitrogen
USDA	United States Department of Agriculture
UUN	Urinary urea nitrogen
UUNY	Urinary urea nitrogen yield
UVR	Utility value reflection
UW	University of Wisconsin
VFA	Volatile fatty acid
WI	Wisconsin

ABSTRACT

This dissertation describes research in two areas: I) on dairy protein nutrition, productivity, and environmental impacts, and II) on teaching and learning in animal and dairy sciences (AnDySci).

Research in Part I addresses the influence of lactating cow protein nutrition on animal outputs valued by humans (e.g., milk protein), outputs associated with environmental risks (e.g., urinary urea-N, greenhouse gas emissions), and mechanisms affecting N metabolism at the whole-animal scale. Chapter 1 introduces the N cycle, N-associated environmental impacts from dairy production, and strategies to reduce N environmental impacts.

The central evidence in Part I stems from a Latin Rectangle trial with n = 16 lactating Holsteins fed four dietary treatments. Treatments represented a 2x2 factorial with two levels of crude protein (low protein [LP], 13.8%; high protein [HP], 15.5% of dry matter [DM]) and two feeding patterns (CP oscillating ± 1.8% of DM every 48 h and CP static) In this study, milk and component production, body weight, and body condition score were measured for all cows. From a subset of cows with ruminal cannulas, we collected the total volumes of urine and feces and sampled rumen fluid, plasma, urine, and feces during d 25 to d 28.

Chapter 2 describes how these treatments affected milk and component production, averaged across 4-d of sampling and disaggregated by twice daily milking timepoints. We found that production of most milk components was unaffected by CP level and feeding pattern, suggesting that productivity was resilient to oscillating dietary CP even when the average level of dietary CP was low relative to predicted requirements. With the oscillating feeding pattern, cosinor mixed models showed wave-like responses in milk urea-N at a 2-d delay relative to dietary changes. This suggested that milk urea-N was responsive to dietary changes even after

adaptation to time-varying diets, which suggests the potential of milk urea-N as an indicator of variability in dietary N availability.

Chapter 3 shares how dietary treatments affected ruminal parameters, digestibility, N balance, N efficiency, and greenhouse gas emissions. Contrary to our hypotheses, CP feeding pattern had minimal effects on measured variables, regardless of the average CP level. Ruminal ammonia-N concentrations were greater for HP, but unaffected by feeding pattern. Similar concentrations of other ruminal analytes suggested that fermentation patterns were not altered by treatment conditions, and this finding was corroborated by a lack of treatment effects on nutrient digestibility. The higher dietary CP condition increased outputs of urinary urea N and reduced N use efficiency, but had no effect on enteric methane production, yield, or intensity. Results indicated that oscillating CP feeding pattern had no effect on environmental outputs from lactating cows, but greater dietary CP led to increased manure N excretion.

Part I concludes with Chapter 4, which summarizes future research areas related to CP level and CP feeding pattern in lactating cows. It summarizes how different experimental designs, methods, and conceptualizations of protein nutrition can contribute to balancing animal productivity and health with reductions in environmental impacts.

Research in Part II focuses on AnDySci education at U.S. institutions (Ch. 5, 6, 7, 8) and contextualized in the author's home department, University of Wisconsin—Madison Animal & Dairy Sciences (Ch. 9, 10). As discussed in Chapter 5, AnDySci education has a rich history at Land Grant institutions that is exemplified in its signature pedagogies. AnDySci postsecondary education is transforming as the industry adapts to increasing structural consolidation, tackles social and interdisciplinary challenges, and works toward greater diversity and inclusion. However, the transformative potential of postsecondary AnDySci education to is hindered by a lack of clarity surrounding assessment and promotion of teaching excellence.

Chapter 6 includes results from a national survey of AnDySci instructors (n = 90) and reviews research on AnDySci teaching and learning from 2008 to 2020. Consistent with the signature pedagogies discussed in Chapter 5, survey results showed that discipline-specific competencies and core experiential learning modalities were rated most important by AnDySci instructors. Results from the scoping review suggested that limited research has assessed transferable skills related to communication, interpersonal interactions, and business. Still, the growing number of publications on active learning in AnDySci may reflect increased focus on non-content, transferable skills.

Chapter 7 transitions to experimental work. It describes a randomized trial evaluating written reflections designed to improve situational interest of introductory AnDySci students. Compared to a control picture summarization task, a reflection activity designed to enhance task value improved situational interest for students with low initial individual interest in animal sciences. Qualitative responses showed that the reflection prompted students to reflect on utility value, intrinsic value, and attainment value. Overall, results showed that reflection activities led to greater situational interest for low-interest learners but had no effects on semester performance.

Chapter 8 delves into methodological issues associated with repeated measurements of student interest using self-report instruments and describes longitudinal growth in individual interest with a latent growth model. After removing two problematic items, we sequentially imposed constraints to test for configural, metric, and scalar measurement invariance. Results showed that the majority of items functioned similarly across the four measurement periods in the experiment. By fitting longitudinal growth curve models, we showed that individual interest started high and followed a curvilinear pattern in one semester (Fall 2018) but followed no significant shape parameters in a subsequent semester (Spring 2019). These findings may relate to the high level of interest on average, heterogeneity of trajectories between students, and low sample size.

Chapter 9 is a cross-sectional observational study of teaching practices and student perceptions in the University of Wisconsin—Madison AnDySci department during the transition to emergency remote learning in the COVID-19 pandemic. Instructor surveys showed how teaching practices transitioned from synchronous in-person learning to synchronous or asynchronous emergency remote learning. Extending on the Community of Inquiry model, we found that student ratings of social presence in their classes were related to their engagement and satisfaction during emergency remote learning. In open-ended responses, students shared about how the transition to emergency remote learning affected their engagement in courses.

Chapter 10 is a mixed-methods case study that introduces a student-led, place-based tour designed acclimatize new AnDySci students to their physical, cultural, and social surroundings. An end-of-semester survey, students reported that the tour helped them locate important campus facilities, helped them build peer relationships with their peers, and to a lesser extent, it introduced them to the AnDySci department's cultural heritage. Observations from the research team detailed how the activity was adapted post-pandemic.

Finally, Chapter 11 summarizes future research directions that can contribute to modernizing and humanizing AnDySci postsecondary education. I make three main arguments. First, that AnDySci education research must extend beyond attributing individual differences to simplistic demographic variables, and instead acknowledge learning as a dynamic process situated within a rich sociocultural milieu. Second, that reports of course performance are neither generalizable nor relevant to pedagogical reform. Third, that drawing from theories and methods in educational psychology and related discipline-based education research can improve the validity of inferences in AnDySci education research. Teaching and learning research has the potential to catalyze grassroots AnDySci educational reform affecting multiple levels: classroom, department, and nation.

CHAPTER 1. N TRANSFORMATIONS IN DAIRY SYSTEMS

1.1 Literature Review

1.1.1 The N cycle in a dairy system

The N cycle describes a set of chemical and physical transformations associated with N compounds that spans across the atmosphere, lithosphere, hydrosphere, and biosphere (Keeney and Hatfield, 2008). The N cycle is among the major biogeochemical cycles required for ecosystem functioning on earth and is interrelated with cycling of water and other nutrients such as C and P (De Vries et al., 2009; Fowler et al., 2013). In dairy production, N availability is a critical factor in determining yields from crop and livestock systems (Rotz et al., 1999). Although the N cycle is core to economic functioning of dairy systems, dysfunctional N management can lead to adverse environmental effects. Critically, each step in the N cycle has the potential to affect subsequent steps (Chadwick et al., 2011). In a dysfunctional N cycle, this can lead to cascading negative environmental effects. For example, the same N molecule can potentially worsen air quality (as atmospheric PM2.5), cause ecotoxic effects (after terrestrial deposition), and contribute to greenhouse gas emissions (as N_2O). This complexity complicates attribution of the sources of N pollution.

For the context of environmental regulations, agencies generally define "reactive N" categorically, as any N species aside from atmospheric N_2 (IFSM, 2015). However, the reactivity of various N species is a continuum and is context-dependent. Nitrogen environmental reactivity depends on the molecule's chemical properties (reactivity) and physical properties (volatility, solubility, radiative efficiency; Luo et al., 2022). From least to most environmentally-reactive, N compounds can be grouped into elemental dinitrogen, high molecular weight organic compounds (e.g., polymers), low molecular weight organic compounds, and inorganic compounds (excluding N_2). In dairy systems, low molecular weight organic compounds such as urea, and inorganic compounds such as nitrate, nitrite, ammonia, nitrous oxides, and nitric oxide pose the greatest environmental risks (Rotz, 2018). For this dissertation, which focuses on major N flows directly associated with lactating cows, reactive N will be operationally defined as urinary urea-N.

In addition to discussing N losses based on N species, reactive N losses can be categorized by the sink (atmosphere or hydrosphere), the chemical reaction modulating the loss (e.g., volatilization, leaching and runoff, nitrification and denitrification). and the farm processes associated with loss (e.g., fuel combustion, resource production, housing, manure storage, manure application). This review will focus on biological N flows associated directly with the animal, which have the potential to affect N losses downstream (Misselbrook et al., 2005). Reactive N losses associated with upstream N losses such as fuel combustion and resource production will not be discussed.

N flows on dairy farms pose risks to air quality, water quality, and climate change (Powell and Rotz, 2015). Volatilization of reactive N such as ammonia and nitrogen oxides affects air quality locally and globally (Pinder et al., 2004). Rotz et al. (2021) estimated that the dairy industry contributed 19-24% of total U.S. ammonia emissions, making the industry a large contributor at the national scale. Reactive N compounds such as nitrate, ammonium, and urea affect water quality. Studies have shown that dairy systems can contribute substantially to nitrate contamination of groundwater at the regional scale, although impacts at a national scale are unclear (Rosenstock et al., 2014). Finally, certain reactive N transformations lead to the formation of nitrous oxide (N_2O), a potent greenhouse gas with a 100-year global warming potential 273 times that of CO_2 (US EPA, 2023). Recent estimates suggest that the dairy industry accounts for 1.5 to 1.9% of U.S. greenhouse gas emissions on a carbon equivalent basis, and that N_2O emissions account for a smaller fraction of dairy emissions compared with other greenhouse gases such as methane (Thoma et al., 2013; Rotz et al., 2021).

Biological and synthetic N fixation

Elemental N (N_2) gas constitutes 78% of the atmosphere and is relatively inert due to its strong triple bond (Keeney and Hatfield, 2001). Eukaryotic organisms such as animals, plants, fungi, and protists cannot use N_2. Instead, eukaryotes rely on organic N from the few prokaryotic genera capable of biological N fixation, such as the bacteria *Rhizobium, Frankia, Azotobacter,* and *Clostridum* (Sprent et al., 1997). Whereas free-living bacteria such as *Azotobacter* and *Clostridum* fix N non-symbiotically, other bacteria including *Rhizobium* and *Frankia* evolved a symbiotic relation with some leguminous plants. This symbiosis manifests in specialized plant root (or sometimes stem) organs called nodules. Invading bacterial species stimulate an extensive nodulation process in the plant (Bergersen, 1982). Inside the nodules, several intricate plant-bacterial interactions occur (Keeney and Hatfield, 2001). The plant's photosynthetic carbohydrates provide energy to the bacteria. The bacterial nitrogenase enzyme system fixes N_2 to NH_3, making the N usable to the plant. The plant and bacteria jointly produce leghemoglobin, an oxygen-carrying molecule. Leghemoglobin solves a paradox: *Rhizobium* are strict aerobes that require oxygen for cellular respiration, but free oxygen in the plant nodule cell cytoplasm would inhibit nitrogenase activity and suppress N fixation (Masson-Boivin and Sachs, 2018). Leghemoglobin binds free oxygen but facilitates oxygen transport to bacteroids, providing for bacterial needs while maintaining a favorable environment for N-fixation. In addition to biological N fixation, a small amount of atmospheric N is deposited when electrical energy in lightning breaks N_2bonds, freeing N to react with oxygen and water and fall to the earth in raindrops (Noxon, 1976).

Prior to the 20th century, N fixation occurred only through biologic means. In the early 20th century, Fritz Haber developed a synthetic process to fix N, in which NH_3 was synthesized chemically from nitrogen and hydrogen. Carl Bosch subsequently developed the means to apply synthetic N fixation on an industrial scale (Smil, 2004). In agriculture, this Haber-Bosch process was used to produce fertilizers throughout the ensuing decades. By the end of the 20th century, researchers estimated that increases in agricultural productivity due to Haber-Bosch-fixed N were responsible for feeding around half (48%) of the global human population (Erisman et al., 2008). However, synthetic N has massively altered the global N cycle and is a major cause of climate change and environmental degradation (Rockström et al., 2009).

Mineralization and immobilization

Mineralization refers to the decomposition of organic N compounds to inorganic compounds such as ammonia (Grzyb et al., 2020). Conversely, immobilization refers to the conversion of inorganic N to organic forms. Both processes are facilitated by microbes. The rates of mineralization and immobilization depend on the chemical composition, temperature, moisture, and microbial characteristics. After manure application to soils, the net mineralization rate (mineralization – immobilization) determines the N available for plant use. Nitrogen mineralization rates are highly variable (Van Kessel and Reeves, 2002). Studies of net available N during storage suggested that about 5% of organic N was made available per day under typical conditions (net N mineralization rate = 0.052/d, IFSM, 2015). The carbon-to-nitrogen (C:N) ratio has drastic implications on rates of N mineralization and immobilization. Greater C:N ratios lead to a greater extent of immobilization, and lesser C:N ratios favor mineralization (Dannehl et al., 2017). This means that manure with greater C:N ratio has greater potential to sequester C and N in soils, although N cycling varies dramatically for different soil types (Powell et al., 2006).

Strategies that reduce manure N excretion generally increase the C:N ratio in manure, which can further decrease N emissions and effluents. In dairy systems, lower dietary CP and greater dietary fiber can result in lower net mineralization rates (Dijkstra et al., 2011). However, Dijkstra et al. (2011) found that greater manure C:N ratio in dairy cattle was possibly related to greater enteric methane emission, illustrating potential trade-offs. With respect to manure emissions after field application, Watts et al. (2007) exposed manure-amended soil samples to wetting and drying cycles under different temperature conditions (11, 18, and 25°C), compared to constant water provision. They found mineralization rate was greatest at 25°C and was unaffected by the moisture cycling routine. Other authors have shown that soil microbial community structure is related to temperature and moisture (Lauber et al., 2013) and affected by organic and inorganic fertilizer applications (Chaudhry et al., 2012), with implications on net N mineralization (Ouyang and Norton, 2020). These studies illustrate that balancing the fertilizer value of manure N with potential N environmental risks is complex and context-dependent.

Volatilization and deposition

Nitrogen volatilization refers to the conversion of N compounds to gaseous form. The predominant N compound volatilized in dairy systems is ammonia (Chadwick et al., 2011). Nitrogen volatilization is affected by physical conditions such as pH, temperature, exposed surface area, and wind speeds (Hristov et al., 2011). Gaseous reactive N compounds readily bind to particles in the air, forming PM2.5 such as ammonium nitrate and ammonium sulfate (Copeland, 2012). Based on speciation studies, reactive N contributes to the formation of 40% of PM2.5 in the U.S. (Liu et al., 2022). Reactive N in air continues through the N cycle when it is deposited with precipitation (wet deposition) or without precipitation (dry deposition; Zhang et al., 2021). According to Benish et al. (2022), the average total N deposition (wet and dry) in contiguous U.S. regions was 6.3 kg N / ha / yr in 2017. Dry deposition ranged from 42 to 83% of total N, with the remainder representing wet deposition.

Runoff and leaching

Dairy N flows affect water quality directly via leaching and runoff, collectively referred to as N effluents. Nitrogen leaching occurs when N molecules infiltrate the soil and enter the groundwater. Nitrogen runoff refers to N entry to surface waters (Keeney and Hatfield, 2008). Although leaching and runoff are natural aspects of the N cycle, geographic consolidation of dairy operations and the increased use of synthetic N fertilizers has necessitated management of these N flows associated with dairy farms. Ammonia, nitrate, and urea are small, water-soluble N molecules that can leach and runoff in water (Vadas and Powell, 2013). Leaching and runoff depend largely on the chemical and physical interactions between manure, soil, and water (irrigation or rainfall; IFSM, 2015). For example, most soils are negatively charged. Therefore, soils have minimal capacity to retain negatively charged molecules such as nitrate. Sandy soils typically have a lower cation exchange capacity, reducing their ability to bind positively-charged ions such as ammonium (Li et al., 1997). High-intensity rainfall events can saturate the soil and wash out N to a greater extent than rainfall that is more distributed across time (Del Grosso et al., 2012).

Nitrification and denitrification

Nitrification is the enzymatic oxidation of NH_4+ to nitrate under aerobic conditions. Denitrification is the enzymatic reduction of nitrate to N_2 under anaerobic conditions. Both reactions produce NO and N_2O as intermediates. Moisture, temperature, pH, and the concentrations of reactants affect the extent of N_2O emissions (Del Grosso et al., 2012). Higher moisture conditions create an anaerobic environment that favors denitrification. Practices that create an aerobic environment increase nitrification (accumulation of dry manure in housing, solid manure storage, or crust formation with liquid manure storage; Aguerre et al., 2012; Aguirre-Villegas and Larson, 2017). Because nitrate is both a product of nitrification and a reactant in denitrification, these reactions interact to determine N_2O emissions (Wattiaux et al., 2019).

Plant uptake

Most plants can uptake the inorganic N species nitrate and ammonia (Mokhele et al., 2012). In many soils, these inorganic N species supply most of the N assimilated by the plant. However, there is evidence to suggest that wild and agricultural plants can also uptake AA and may indeed secrete proteases from their roots (Godlewski and Adamczyk, 2007). Plant growth and development are the major factors affecting N demands. During early vegetative stages, the plant accumulates tissue rapidly and demands N roughly proportional to its growth in dry matter (Schenk, 1996). After reproductive maturity, N demands decline, and there is evidence that the plant can translocate N from vegetative to reproductive tissues, therefore requiring less N from soil (Xing et al., 2019).

1.1.2 N flows from lactating cows under typical feeding conditions

Based on a meta-analysis of N balance experiments (n = 86) over 24 years by Spanghero and Kowalski (2021), major N flows (mean ± SD) for a typical lactating cow include intake (572 ± 114 g/d), fecal excretion (192 ± 42 g/d), urinary excretion (186 ± 61 g/d) and secretion in milk (155 ± 34 g/d). In typical N balance experiments, accretion or loss of body N is not measured directly. The residual N intake not accounted for in feces, urine, and milk is sometimes assumed to represent changes in body N. However, residual N is a poor indicator of actual body N accretion for several reasons. First, residual N is calculated by difference, so it accumulates the error associated with measurement of other N pools and typically has a large standard deviation. Second, residual N is biased positive, which contrasts the expectation that mean residual N should equal zero (Spanghero and Kowalski, 1997, 2021). Finally, residual N values sometimes imply rates of body N accretion that are unrealistic or do not match recorded body weight changes (Hristov et al., 2019). For example, assuming 8% of empty body weight gain is crude protein NASEM, 2021), the mean retained N of 38.5 g observed by Spanghero and Kowalski (2021) implies empty body weight gain of approximately 3 kg/d, which is not physiologically realistic under many typical dietary and animal conditions. For these reasons, short-term experimentation is sometimes done under the pretense of steady-state or near-steady-state conditions.

Intake N

N intake is largely determined by the crude protein (**CP**) concentration of the diet fed (Ferreira et al., 2021). However, dietary protein amount and composition can influence voluntary intake, making it less straightforward to manipulate dietary N intake by altering diet CP concentration. For example, feeding trials have shown dietary CP can affect intake by increasing rumen passage rates, decreasing rumen distension and increasing intake (Hristov et al., 2004; Schwab et al., 2005; Schwab and Broderick, 2017). Conversely, a meta-analysis by Martineau et al. (2016) illustrated that casein infusion decreased dry matter intake (**DMI**) for cows in positive metabolizable protein (**MP)** balance, which may indicate hypophagic effects of excess amino acid **(AA)** oxidation (Allen, 2020). Interestingly, a meta-analysis by Huhtanen and Hristov (2009) showed that N use efficiency was more related to dietary CP concentration than to dietary N intake.

Fecal N

Fecal N constitutes mainly undigested feed N and undigested endogenous N from gastrointestinal sloughing and secretions (in Ouellet et al., 2002, 83% of 17% of fecal N flow, respectively). As emphasized by Weiss and Tebbe (2019), digestibility is a property of the system of animal and diet. As a consequence, both animal and diet factors interact to affect fecal N excretion. Greater DMI and dietary neutral detergent fiber (**NDF**; % of diet DM) can increase endogenous N excretion (2019). Feed factors that affect organic matter (**OM**) digestibility such as feed type (concentrate vs. forage), feed processing, and fiber content are also related to fecal N excretion (Huhtanen et al., 2009; Nousiainen et al., 2009). Generally, greater DMI increases rate of passage and suppresses digestibility, which suggests greater DMI increases the excretion of undigested feed N in feces (Huhtanen et al., 2009). Due to differences chemical composition, fecal N is more storage-stable and poses fewer environmental risks compared with urinary N (Dijkstra et al., 2013a). Therefore, dairy nutrition studies aimed at reducing N outputs have often focused on urinary rather than fecal N (Steinfeld et al., 2006).

Urinary N

Meta-analyses have shown a close, positive linear relationship between dietary CP concentration and urinary N output (Powell et al., 2011; Spek et al., 2013a). Urinary N is predominantly urea-N (81 to 84% of urinary N in Wattiaux and Karg, 2004) which results largely from AA deamination and the subsequent hepatic conversion of ammonia to urea. Although some urinary urea-N excretion is expected even with minimal dietary CP intake (Lapierre et al., 2020), much of the variation in urinary urea-N appears linked to protein nutrition (Spek et al., 2013b). Besides urea-N, other nitrogenous components in bovine urine include purine derivatives, creatinine, hippuric acid, and free AA. Purine derivatives such as allantoin, uric acid, and xanthine + hypoxanthine are metabolic byproducts resulting from the degradation of rumen microbial nucleic acids (Valadares et al., 1999). Briefly, xanthine and hypoxanthine are oxidized to uric acid by xanthine oxidase in the intestinal mucosa, liver, and blood. Uric acid is oxidized to allantoin by urate oxidase (Prahl et al., 2022). As such, purine derivative excretion is proportional to the passage rate of microbial biomass, and certain purine derivative such as allantoin are routinely used to estimate microbial protein synthesis (Broderick and Merchen, 1992). There are some species differences among ruminants. For example, unlike ovine plasma, bovine plasma contains the enzyme xanthine oxidase which convers xanthine to uric acid (Bristow et al., 1992). This reaction increases uric acid and decreases xanthine concentrations in bovine compared with ovine urine. Although 95-99% of all blood AA are reabsorbed by the kidney (Bröer, 2008), reabsorption is incomplete and rates vary by each AA (Eaton et al., 1945). As a result, bovine urine contains small amounts of free AA such as creatine, glycine, taurine, alanine, 3-methylhistidine, and 1-methylhistidine. Creatine is derived from Gly, Arg, and Met. When creatine is phosphorylated by creatine kinase to phosphocreatine, it is used to store energy in the skeletal muscle and brain (Sadri et al., 2023). Within skeletal muscles, creatine is non-enzymatically and irreversibly degraded at a relatively constant rate, producing creatinine (Wyss and Kaddurah-Daouk, 2000). Creatinine excretion is predominantly determined by glomerular filtration because little reabsorption occurs. Therefore, urinary creatinine excretion can be used as an indicator of kidney function as well as body skeletal muscle reserves (Valadares et al., 1999; Megahed et al., 2019). Whereas creatinine is excreted at a relatively constant rate proportional to skeletal muscle mass, 3-methylhistidine is a component of myofibrillar proteins actin and myosin that is released to circulation as a result of skeletal muscle protein degradation (Young et al., 1970). Greater blood and urinary 3-methylhistidine indicate a greater extent of skeletal muscle breakdown. In some dairy cattle studies, the serum 3-methylhistidine to creatinine ratio has been reported to illustrate the extent of muscle protein breakdown relative to the animal's muscle mass (McCabe et al., 2021; Sadri et al., 2023). Compared to 3-methylhistidine, less work has assessed 1-methylhistidine in dairy cattle. 1-methylhistidine is the breakdown product of the dipeptide anserine (Kubomura et al., 2009). Houweling et al. (2012) showed that concentrations of 1-methylhistidine and 3-methylhistidine were similar on average, but the relative concentrations varied across the periparturient period. Hippuric acid is produced when the liver detoxifies benzoic acid by conjugating it with glycine. Benzoic acid results from the digestion of phenolic compounds, which are secondary metabolites ubiquitously distributed throughout plant tissues. Interestingly, hippuric acid has been proposed as both a nitrification inhibitor and an indicator of plant digestibility (Dijkstra et al., 2013a). Hippuric acid excretion is expected to represent a small, relatively constant fraction of urinary N excretion unless the diet is modified through the addition of phenolic compounds such as tannins and anthocyanins (Gao and Zhao, 2022).

Milk N

Most milk N is true protein, with a lesser fraction of N from milk urea (approximately 95 and 5%, respectively, in NASEM, 2021). Protein nutrition affects milk protein synthesis both because intestinally-absorbed AA serve as the substrate for milk protein synthesis in mammary epithelial cells, and because AA exert signaling effects locally and systemically (Appuhamy et al., 2014). Researchers have shown that the relative supplies of individual AA, groups of AA, and energy can add and interact to determine milk protein yield (Bequette et al., 2000; Omphalius et al., 2019; Danes et al., 2013). In general, as dietary CP concentration increases, milk true protein yield increases to a maximum with gradually diminishing returns. After milk true protein yield is maximized, additional CP has minimal or negative effects on milk true protein yield. This response has often been modeled with piecewise ("broken-stick") and polynomial (positive linear and negative quadratic coefficients) functions (NASEM, 2021). Recent studies showed that responses in milk true protein yield due to dietary CP were primarily associated with changes in milk yield rather than milk true protein concentration (Barros et al., 2017; Letelier et al., 2022). The concentration of MUN has a close, linear, positive relationship with dietary CP (Powell et al., 2011). As dietary CP increases, MUN yields generally increase (Ferreira et al., 2021) although the relationship is less clear than that of MUN concentration and CP.

1.1.3 Strategies to reduce N environmental impacts from the lactating dairy cow

At the animal level, researchers have conceptualized the objective to reduce dairy N environmental impacts in three major ways: 1) to reduce the total amount of N or reactive N output in manure per animal (animal-level N output), and 2) to reduce the total N or reactive N output in manure per unit productive output (animal-level N footprint), and 3) to increase the N output in milk relative to N intake (animal-level N use efficiency). Under steady state conditions, i.e., no N loss or gain to the animal's body, reducing the N footprint is conceptually equivalent to improving N use efficiency. Importantly, productive output can be considered variously, e.g., in terms of milk N, milk true protein, or fat-and-protein-corrected milk. Some authors have even operationalized "productive N" as the sum of milk N and body N accretion (Tebbe and Weiss, 2020). Major influences on N utilization include 1) the amount of CP supplied per day, 2) the composition of CP, and 3) CP digestion kinetics and interactions with other nutrients.

Reducing dietary CP has been shown to reliably decrease total N and reactive N excretion in manure at any level of CP intake (Dijkstra et al., 2013b). When supplies of AA are not limiting milk protein production, it is possible to reduce dietary CP while maintaining or sometimes increasing productivity (NASEM, 2021). Conversely, negative outcomes have been documented in response to reduced-CP diets. Possible negative outcomes include reductions in DMI (Barros et al., 2017), suppression of rumen fermentation and nutrient digestibility (Belanche et al., 2012), reduced productivity (Letelier et al., 2022), losses of body reserves (Liu et al., 2021), and reduced immune function (Raggio et al., 2007; Coleman et al., 2020). Reducing dietary CP is low-cost, feasible across regions and production systems, and unlikely to result in downstream "rebound" or "pollution-swapping" effects (Zhang et al., 2019; Rotz et al., 2021). Recently, Morey et al. (2023) illustrated how precision protein feeding based on individual cow requirements could reduce N excretion.

The composition of protein has the potential to affect N excretion because urinary urea-N excretion is greater with diets where AA digestible supplies (g/d) are mismatched with animal needs (Patton et al., 2014). Digestion kinetics affect CP utilization, because supplying CP that is quickly and extensively degraded in the rumen can exceed the capacity of the ruminal microbiota to assimilate ammonia, elevating blood urea levels and increasing urinary urea N excretion (Agle et al., 2010). Protein utilization efficiency in the rumen and post-absorption also depends on metabolism of other nutrients. For example, Roman-Garcia et al. (2016) found that the outflow of rumen microbial N was related to dietary amounts of rumen fermentable fiber and carbohydrates. Post-absorption, Omphalius et al. (2019) showed that higher energy diets increased mammary plasma flow and affected mammary AA uptake. These studies illustrate that numerous dietary interventions may improve the utilization of N through multiple mechanisms.

1.1.4 Oscillating dietary crude protein

Researchers have attempted to leverage these physiological adaptations by altering CP feeding patterns between N excesses to deficiencies as a means to induce compensatory efficiency in growing sheep (Simpson, 2000; Kiran and Mutsvangwa, 2009; Doranalli et al., 2011), growing beef cattle (Ludden et al., 2003; Menezes et al., 2019a; b), and finishing beef cattle (Simpson, 2000; Cole et al., 2003; Archibeque et al., 2007). These studies showed few differences in growth and carcass performance and possible improvements in N retention. Many experiments on beef cattle and sheep tested 24- and 48-h oscillation phases. Cole (1999) suggested that oscillating CP feeding patterns may be most effective when dietary changes are synchronized with the approximate retention time of digesta in the gastrointestinal tract (Cole, 1999).

At the time of writing, few studies have examined oscillating dietary crude protein in dairy cattle. In an early study on oscillating dietary CP feeding pattern in lactating dairy cattle, Brown (2014) fed diets alternating from 10.4 to 16.4% CP in 48-h phases, relative to a static 13.4% CP control. Milk production and DMI were similar but there was a tendency for decreased component production. Because milk yield decreased on the second day of low dietary CP, the author speculated oscillating CP at these levels on 48-h phases exceeded the cows' ability to maintain production and recommended oscillation phases less than 48 h. Kohler (2016) subsequently tested three oscillation phases—24 h, 48 h, and 72 h—with low (14.3%) and high (20.3%) CP relative to a static control (17.1% CP). Compared with static CP feeding, all oscillating CP feeding patterns resulted in similar milk production, increased MUN, decreased milk protein yield, and greater apparent N retention. Few differences were apparent between treatments differing in phase duration. Although faster rates of passage are likely for lactating dairy cattle consuming rations with higher forage quality (e.g., Brown, 2014; Kohler, 2016) compared to the sheep and beef cattle of earlier experiments (e.g., Ludden et al., 2003; Archibeque et al., 2007; Doranalli et al., 2011) both the phase duration and the amplitude of ingredient changes challenge the lactating cow's adaptability to N deficiencies and excesses.

Whereas Brown (2014) tested oscillating vs. static CP feeding pattern at an overall MP deficiency and all diets tested by Kohler (2016) likely exceeded MP requirements, Tebbe and Weiss (2020) compared oscillating and static CP feeding patterns at 95% of MP and 86% of RDP requirements based on NRC (National Research Council (NRC), 2001). In the latter study, diets oscillated in 24-h phases from 11.9 to 16.2% CP were compared to both an equivalent (14.1% CP) and a positive (16.2% CP) static control, but milk yield and other milk components were unaffected by CP feeding pattern. Similar to Kohler (2016), Tebbe and Weiss (2020) observed increased MUN and decreased milk protein yield with the oscillating CP feeding pattern. Apparent digestibility of most nutrients was similar, except that oscillating feeding improved CP digestibility. In a subsequent study, Rauch et al. (2021) returned to 48-h phases but tested ingredient changes of lesser amplitude. Compared to a static (14.9% CP) control, diets that oscillated from 13.4 to 16.5% CP produced no differences in milk production, component production, or component concentration with the exception that MUN was greater on the oscillating CP feeding pattern, similar to previous work (Kohler, 2016; Tebbe, 2020). Although both CP feeding patterns in Rauch et al. (2021) likely met MP requirements, diets were formulated to be deficient in RDP relative to rumen fermentable carbohydrates, similar to Tebbe and Weiss (2020).

Generally, these studies on oscillating dietary CP in dairy cattle studies demonstrated that productive performance was resilient to day-to-day changes in dietary N availability when longer-term requirements were satisfied (Kohler, 2016; Tebbe and Weiss, 2020; Rauch, 2021), relative to static feeding. However, differential responses were observed that raised questions about the duration of oscillation phases, the amplitude of ingredient and nutrient changes, and the extent to which putative N-conserving mechanisms contributed to maintaining production during periods of deficiencies.

Based on research with different levels of static dietary CP, oscillating feeding patterns may theoretically affect numerous N dynamics and N pools related to dietary protein intake. Dietary CP intake has been shown to affect the rates of hepatic urea synthesis and re-entry into the gastrointestinal tract (Lapierre and Lobley, 2001), the rate of urea clearance in the urine (Røjen et al., 2011) the chemical and species composition of the rumen microbiota (Bach et al., 2005), the efficiency of mammary AA extraction (Arriola Apelo et al., 2014), and whole-body rates of protein synthesis and degradation (Liu et al., 1995). Therefore, it is reasonable that these processes may be altered by periodic dietary CP excesses and deficiencies when fed in an oscillating CP pattern. It is unknown how alterations in nutrient metabolism associated with feeding pattern would affect milk and component production and environmental outputs such as greenhouse gases and urinary urea N.

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CHAPTER 2. DYNAMIC LACTATION RESPONSES TO DIETARY CRUDE PROTEIN OSCILLATION IN DIETS ADEQUATE AND DEFICIENT IN METABOLIZABLE PROTEIN IN HOLSTEIN COWS

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2.1 Abstract

Limited research has examined the interaction between dietary crude protein (CP) level and CP feeding pattern. We tested CP level (low protein [LP], 13.8%; high protein [HP], 15.5% of dry matter [DM]) and CP feeding pattern (OF = oscillating, SF = static) using a 2x2 factorial in 16 mid- to late-lactation Holsteins (initially 128 ± 12 days in milk; mean ± SD). Cows ate total mixed rations formulated by exchanging soy hulls and ground corn with solvent soybean meal to keep constant ratios of neutral detergent fiber to starch (1.18:1), rumen-degradable protein:CP (0.61:1), and forage:concentrate (1.5:1) in DM. The OF treatments alternated diets every 48 h to vary CP above and below the mean CP level (OF-LP = 13.8 ± 1.8%; OF-HP = 15.5 ± 1.8% CP of DM) whereas diets were constant in SF (SF-LP = 13.8%; SF-HP = 15.5% CP of DM). In 4 28-d periods, 8 rumen-cannulated and 8 non-cannulated cows formed 2 Latin Rectangles. On d-25-28 of each period, each cow's feed intake and milk production was recorded and samples were taken of orts (1x/d) and milk (2x/d). We fit linear mixed models with fixed CP level, CP feeding pattern, and period effects, and a random intercept for cow; computing least squares means and standard errors. Neither CP level, CP feeding pattern, nor the interaction affected DM intake, feed efficiency, or production of milk, fat-protein-corrected milk, fat, true protein, or lactose. Milk urea-N (MUN) yield was lesser for LP. The LP and OF conditions decreased MUN concentration. The CP level tended to interact with CP feeding pattern so that milk protein concentration was greatest for OF-HP. The OF and LP conditions increased the ratio of true protein to MUN yield. Within OF, cosinor mixed models of selected variables showed that cows maintained production of fat-protein-corrected milk across dietary changes but MUN followed a wave-pattern at a 2-d delay relative to dietary changes. A tendency for lesser MUN with OF contradicted prior research and suggested potential differences in urea-N metabolism between OF and SF. Results showed that cows maintained production of economically-relevant

components regardless of CP feeding pattern and CP level. Contrary to our hypothesis, the effects of 48-h oscillating CP were mostly consistent across CP levels, suggesting that productivity is resilient to patterned variation in dietary CP over time even when average CP supply is low (13.8% of DM) and despite 48 h restrictions at 12.2% CP.

2.2 Introduction

Most ruminant nutrition research considers the ability of constant-composition diets to meet daily dietary protein requirements, yet ruminants rely on evolutionary mechanisms that theoretically cushion responses to dietary CP excesses and deficiencies spanning several days (Lapierre and Lobley, 2001). Researchers have attempted to leverage these physiological adaptations by altering CP feeding patterns between N excesses to deficiencies as a means to induce compensatory efficiency in growing sheep (Simpson, 2000; Kiran and Mutsvangwa, 2009; Doranalli et al., 2011), growing beef cattle (Ludden et al., 2003; Menezes et al., 2019a,b), and finishing beef cattle (Simpson, 2000; Cole et al., 2003; Archibeque et al., 2007). Several recent studies in mid-lactation dairy cattle observed limited changes to milk and component production compared with static feeding when the ingredient composition of 5-10% of dietary DM was alternated at regular intervals to create short-term restrictions in MP, RDP, or both MP and RDP (Brown, 2014; Kohler, 2016; Rauch et al., 2021; Tebbe and Weiss, 2020). In general, these studies showed that dairy cattle maintained performance when fed in oscillating patterns relative to static (Kohler, 2016; Tebbe and Weiss, 2020; Rauch, 2021) except when the duration and amplitude of nutrient changes was too severe (Brown, 2014).

Experiments that introduce variability in nutrient composition over time may contribute to empirical and mechanistic understanding of the extent to which putative N-conserving mechanisms can contribute to maintaining production during periods of deficiencies. However, existing studies on lactating cows have tested oscillating vs. static CP feeding patterns centered at only 1 level of CP, and it remains unclear if the responses in productive performance are sensitive to level of CP interacting with CP feeding pattern. To address this limitation, our first objective was to evaluate performance responses in lactating dairy cows when consuming diets with different CP levels and feeding patterns. Our second objective was to characterize temporal patterns in production responses to the oscillating CP feeding pattern. We hypothesized that CP level and CP feeding pattern would interact such that the oscillating CP feeding pattern would be deleterious to productive performance at lower but not higher dietary CP.

2.3 Materials and Methods

This study occurred at the University of Wisconsin—Madison Dairy Cattle Center during April to August 2021. All procedures involving animals were approved by the University of Wisconsin–Madison Institutional Animal Care & Use Committee (protocol #A006439).

2.3.1 Animals and Experimental Design

We used 16 multiparous Holstein cows (initially 128 ± 12 DIM; mean ± SD) where half of the cows were not cannulated (n = 8) and half were cannulated (n = 8; 10 cm ruminal cannula, Bar Diamond Inc., Parma, ID). Productive performance variables such as DMI, milk production, and component production were recorded for all cows (n = 16). This 2x2 factorial experiment consisted of 4 28-d experimental periods. For each experimental period, cows were assigned to treatments within cannulated and non-cannulated subsets in a replicated Latin Rectangle arrangement. Each period consisted of an adaptation period (d 1-24) followed by a 4-d intensive sampling period (d 25-28). Two cows were removed from the study after contracting toxic mastitis, resulting in the loss of 2 cells (cow-periods) from the Latin Rectangle representing treatments OF-HP and SF-HP. An additional cow was substituted into the design for Period 3-4 after a toxic mastitis case in Period 2. Throughout the experiment, cows were housed in individual tie stalls with rubber mats. Stalls were bedded with wood shavings. Cows were milked twice daily (0400 and 1600 h) and fed a TMR once daily (0800 h) targeting a 5% refusal rate.

Feed was pushed toward cows in the bunk once daily (~1800 h) and cows had free access to automatic waterers. The barn was cooled with an evaporative tunnel ventilation system.

2.3.2 Dietary Treatments

Nutrient and ingredient composition is shown in Tables 1 and 2. Dietary treatments centered on 2 levels of CP (LP = 13.8%; HP = 15.5% of DM), with dietary CP fed in 2 patterns (oscillating or static, OF and SF respectively). Using NRC (2001), we formulated LP to supply less than predicted requirements for RDP and MP and HP to supply adequate RDP and MP. Each OF feeding pattern alternated 2 diets every 48 h to vary CP above and below the mean CP level (OF-LP = 13.8 ± 1.8%; OF-HP = 15.5 ± 1.8% CP of DM) resulting in time-varying dietary CP. In the SF feeding pattern, a single diet was fed throughout the experimental period for each dietary CP level, targeting time-invariant dietary CP (SF-LP = 13.8%; SF-HP = 15.5% CP of DM). Dietary CP composition across an experimental period is shown in Figure 1. All diets had a 60:40 forage-to-concentrate ratio with dietary changes implemented by changing the formulation of a pelleted concentrate blend which included all ingredients except corn silage and alfalfa haylage. Forage composition is shown in Table 3. Soybean hulls, ground corn, and expeller soybean meal were linearly exchanged with solvent soybean meal to alter dietary CP level. This exchange was designed to minimize differences in diet physical properties (particle size, anticipated ruminal digestion and passage kinetics) and to hold constant dietary NDF:starch and RDP:CP ratios.

2.3.3 Measurements and sampling

Cow body weights were recorded prior to feeding and immediately after the 0400 milking on d 22-23 of the experimental period and on d 1-2 of the subsequent period on a scale

(Rice Lake Weighing Systems, Rice Lake, WI; Model 480Plus-2A). The same 3 raters scored body condition in 0.25 increments on a 1 to 5 scale on d 23 to d 28 of each experimental period (Wildman et al., 1982). Diets were mixed using a hydraulic cart (I.H. Rissler, Ephrata, PA; Mobile Forage Blender) equipped with an electronic scale (Avery Weigh-Tronix, Fairmont, MN; Model 640M). Samples of TMR, forages, and orts were oven-dried at 55°C for 48 h for sample preservation and selected samples were further dried at 105°C for 24 h to determine DM. Once per week throughout the experiment, TMR and forage samples were taken and oven-dried to adjust ingredient amounts added to the feed mixer. For each intensive sampling period (d-25 to 28), daily samples of TMR (n = 4) and forages (n = 2) were frozen at -20°C. Batches of samples were thawed at room temperature, oven-dried, ground to pass a 1 mm screen in a Wiley Mill (Thomas Scientific, Swedesboro, NJ), and then composited by volume within diet and period. In each intensive sampling period, each cow's orts were sampled immediately prior to removing them. For a given cow and sampling period, orts from the high phase (d 25-26) and low phase (d 27-28) of the intensive sampling period were composited within-phase, as-is, by volume. Composited orts were oven-dried to enable gravimetric calculation of individual-cow DMI. Milk weights were collected using the parlor flow meters (Perfection 3000 Meter and Sampler, Boumatic, Madison, WI) and recorded manually by farm staff. Milk samples were taken via automatic samplers in the parlor, preserved with bronopol tablets, and refrigerated 1 to 4 d until transportation for analysis.

2.3.4 Laboratory Analysis

Analysis of total N, ash, NDF corrected for starch and ash (aNDFom), ADF corrected for ash (ADFom), and indigestible NDF corrected for ash (iNDFom) in feed occurred at the USDA Dairy Forage Research Center (Madison, WI). The procedure for NDF used a neutral detergent solution with amylase and sodium sulfite (method 2002.04.2005; Mertens, 2002). Residues from NDF and ADF procedures were ashed at 600°C for 2 h to determine NDFom and ADFom (method 973.18, AOAC International, 1996). Indigestible NDF (iNDFom) was determined following incubation of F57 polyester filter bags (25 micron porosity, 5x5 cm, 500 mg sample) for 240 h in the rumen of 2 cows fed a diet similar to experimental diets (major ingredients: alfalfa haylage, corn silage, corn grain). Feed samples were sent to a commercial laboratory for chemical analysis of the other reported nutrients (Dairyland Laboratories, Arcadia, WI). At the commercial laboratory, water soluble carbohydrates were measured using the method of Deriaz (1961), starch was assayed enzymatically (AOAC, 2014), crude fat was determined with diethyl ether extraction (method 920.39, AOAC International, 1996), lignin was determined gravimetrically after neutral and acid detergent treatment and sulfuric acid hydrolysis (method 973.18, AOAC International, 1996), and residues from the ADF and NDF procedures were combusted to determine acid detergent insoluble CP (ADICP) and neutral detergent insoluble CP (NDICP), respectively (method 973.18, AOAC International, 1996). Milk samples were transported to a commercial laboratory for spectrometric analysis of components using a Foss FT6000 (Foss Electric, Hillerød, Denmark; AgSource Laboratories, Verona, WI).

2.3.5 Calculations, Data Processing, and Statistical Analysis

Calculations

Milk N (g) was calculated as (g milk urea-N yield [MUNY]*0.46) + (g true protein/6.38). Apparent N use efficiency (NUE, %) was calculated as [(N in milk true protein)/(N intake) × 100]. Fat- and protein-corrected milk was determined per IDF (2022) as the milk yield (kg) weighted by [(1.226 × milk fat concentration (g/100 g)) + (0.0776 × milk true protein concentration (g/100 g)) + 0.2534)]. Milk net energy was calculated per NRC (2001) equation 2-15.

Missing Data Imputation

In addition to the 2 Latin Rectangle cells removed due to toxic mastitis, a small percentage (0-2%) of milk weights and milk samples were missing due to technical issues such as failure of sampling equipment. To prevent imbalance across timepoints in the aggregate model, we used stochastic regression to impute these miscellaneous missing observations before aggregating to period-level means for each cow. The imputation model contained fixed effects and interactions for known experimental design factors including period (1, 2, 3, 4), milking (0400, 1600), and cow (1 to 17). Each prediction was augmented with a random draw from the observed residual distribution to mitigate variance attenuation (Little and Rubin, 2002).

Aggregation Methods

The DMI was calculated per cow for each day during the intensive sampling period so it corresponded exactly with daily samples of TMR and orts. Then, we aggregated DMI to arithmetic means per cow, per period. Body weight was calculated as the arithmetic mean of n = 4 observations per cow per period. The inter-rater reliability of body condition scores was evaluated using Cohen's kappa statistics with quadratic weights for the ordinal BCS scale. Results indicated moderate pairwise inter-rater reliabilities (κw = 0.50 to 0.61) so the arithmetic mean of BCS was used in further analyses (Cohen, 1968). The average milk component yields concentrations for a given cow and period were computed as weighted averages using the milk composition (%) and milk yield (kg) across morning (n = 4) and evening (n = 4) milkings in d 25-28 during each period.

2.3.6 Statistical Analysis

Statistical analysis was conducted in R version 4.1.2 (R Core Team, 2021). We considered $P < 0.05$ significant and $0.05 \le P \le 0.10$ tendencies. When standard errors differed due to imbalance, we reported the greatest standard error.

A priori contrasts for productive performance

For production and efficiency variables, we modeled the mean of observed values for a given cow and period using a linear mixed model with fixed effects for cannulation status (S_j, where j = cannulated, non-cannulated), experimental period (E_k, where k = 1, 2, 3, 4), dietary CP level (P_l, where l = LP, HP), CP feeding pattern (F_m, where m = OF, SF), and the interaction term between CP level and CP feeding pattern. We included a random effect of cow (where i = 1 to 17) and a random error term (ϵ_{ijklm}; n = 62).

$$y_{ijklm} = \mu + S_j + E_k + P_l + F_m + PF_{lm} + C_i + \epsilon_{ijklm}$$

To model productive performance variables over time, we added fixed effects and all possible interactions for day (D_n, where n = 25, 26, 27, 28) and hour (H_o, where o = a.m. milking, p.m. milking) with treatments, and allowed the intercept to vary based on cow, period within cow, and day within period within cow, creating a block diagonal variance-covariance matrix.

$$\begin{aligned} y_{ijklmno} = \mu + S_j + E_k + P_l + F_m + PF_{lm} + D_n + H_o + (D_n \times H_o) \\ + D_n(P_l + F_m + PF_{lm}) \\ + H_o(P_l + F_m + PF_{lm}) \\ + (D_n \times H_o)(P_l + F_m + PF_{lm}) \\ + C_i + (C{:}E)_{ik} + (C{:}E{:}D)_{ikn} + \epsilon_{ijklmno} \end{aligned}$$

We estimated models with restricted maximum likelihood using the lme4 and lmerTest packages (Bates et al., 2015; Kuznetsova et al., 2017). We computed Type III sums of squares using the afex package (Singmann et al., 2022) to evaluate a priori contrasts comparing differences due to CP feeding pattern, CP level, and their interaction with F-tests. We estimated marginal means using the emmeans package (Lenth, 2016). To examine responses over time, we computed estimated marginal means for each treatment (CP level and CP feeding pattern) at each timepoint (day and hour) marginalized across experimental periods and cannulation status. For the subset of variables where the interaction of CP feeding pattern and day indicated a temporal pattern, we tested a cosinor model.

Cosinor analysis of temporal patterns in milk yield and composition

For the oscillating CP feeding pattern, we tested if selected milk and component variables oscillated at a frequency set by dietary changes. Variables were selected on the basis of a significant CP feeding pattern by day interaction in linear models of productive performance over time. Because we were interested in differences over time for OF, we used only the subset of data when cows were fed the OF CP feeding pattern. We modeled the raw observed values for milk yield and composition at each milking (n = 8) during the intensive sampling period. We tested for oscillation in milk and component values assuming a 96 h period comprised of 2 feeding phases, the high-CP phase (d 25-26) and low-CP phase (d 27-28). With time centered at the time of the first feeding for the high-phase diets (d 25 at 0800 h), milk and component observations spanned -4 h to 84 h (0400 and 1600 h daily) in each sampling period. We fit single component cosinor mixed models of the non-linear form:

$$Y_{ij} = M + A \times cos(\frac{2\pi \, time_i}{period} + \phi) + \epsilon_{ij}$$

Where Y_{ij} is the observed value of milk or component production for a given milking for cow *j*, M defines the MESOR (the rhythm-adjusted mean), A represents the amplitude (half the extent of predicted variation in a cycle), ϕ is the acrophase (the time at which the function is maximized each cycle), and ϵ_{ij} is the error term. We transformed time into 2 new variables, $r_i = cos(\frac{2\pi \text{ time}_i}{period})$ and $s_i = sin(\frac{2\pi \text{ time}_i}{period})$, to estimate the non-linear cosinor model using its equivalent linear form (Mikulich et al., 2003). The model included fixed effects that interacted with the 2 transformed-time variables to influence the MESOR, amplitude, and acrophase: experimental period (1, 2, 3, 4) and protein level (LP, HP). To correct for nuisance variation in milk and component production related to milking time (AM, PM), we added a fixed effect for sampling time that did not interact with transformed-time variables and thus influenced the MESOR but affected neither the amplitude nor acrophase. Finally, we included the random effect of cow (C_j; affecting MESOR) of cow to account for cow-related variance. The observation *i* for cow *j* can be represented as a linear mixed model using the transformed time parameters r_i and s_i as:

$$\begin{aligned} \mathrm{Y}_{ij} = M + \alpha_0 E + \alpha_1 S + \alpha_2 H + \alpha_3 P + \alpha_4 H{:}P + \\ (\beta + \alpha_4 E + \alpha_5 P) r_i + \\ (\gamma + \alpha_6 E + \alpha_7 P) s_i + C_j + \epsilon_{ij} \end{aligned}$$

We estimated cosinor models with restricted maximum likelihood using the lme4 package (Bates et al., 2015). To report model results, we converted acrophase from radians to hours as described by Refinetti (2007) with $\phi' = -\phi(\frac{period}{2\pi})$. We used the "cosinoRmixedeffects" package to generate standard bootstrap confidence intervals for the nonlinear parameters MESOR, amplitude, acrophase, and for the pairwise differences in these parameters based on the covariate CP level (Hou et al., 2021).

2.4 Results and Discussion

Our study examined milk productive performance in response to 2 levels of dietary CP (LP, HP) and 2 CP feeding patterns (OF, SF) in a 2x2 factorial treatment arrangement. The LP treatments were designed using NRC (2001) to impose deficiencies in RDP and MP when averaged over time. Table 4 shows predicted supplies and balances of NEL and MP (NASEM, 2021). Consistent with our design of experimental diets, NASEM (2021) model predictions indicated that energy was oversupplied for all treatments, MP was undersupplied for LP (94% of requirement), and MP exceeded requirements for HP (104% of requirement). Because CP concentration varied ± 1.8% of DM in OF, predicted MP varied substantially for the higher- and lower-CP phases of oscillating treatments (OF-LP = 83 to 104% and OF-HP = 94 to 114% of MP requirement). Thus, our research contributed to understanding the potential interaction between CP level and FP suggested by prior research.

2.4.1 DMI, Body Weight, and BCS

We observed no differences in DMI due to CP level, CP feeding pattern, or the interaction (Table 5). Supplemental Figures show DMI across the 4-d sampling period, which tended to differ slightly from day to day ($P = 0.067$; Table 5), but followed a similar temporal pattern for both OF and SF (D:F interaction, $P = 0.314$; Table 5). The lack of CP level effect on DMI in our trial may be related to the short duration of experimental periods (28-d) or the small magnitude of dietary changes. In a summary of contemporary studies, Sinclair et al. (2014) indicated that the effects of dietary CP on DMI were modest at dietary CP levels of 14% or greater and often confounded with changes in dietary fermentable energy and physical properties. In our trial, lower CP coincided with modest increases in non-forage NDF and starch, with minimal changes in diet physical properties (constant forage:concentrate ratio) and no net effect on DMI.

Similarly, in our trial, DMI was resilient to periodic small-magnitude dietary changes associated with the oscillating CP feeding pattern. This is consistent with recent studies of lactating cows that showed no effect of oscillating CP feeding pattern on DMI relative to static (Kohler, 2016; Tebbe and Weiss, 2020; Rauch et al., 2021). Because the oscillating pattern probably desynchronized the availability of rumen-degradable protein and carbohydrates, our results agree with the literature summarized by Hall and Huntington (2008) in which *in vivo* tests of asynchrony generally produced null results. The duration of higher- and lower-CP phases in our trial was expected to align with the approximate retention time of digesta in the gastrointestinal tract, as in earlier experiments on beef cattle and sheep (Cole, 1999). Effects of CP feeding pattern on DMI may also relate to changes in feeding behavior. For example, simultaneous and successive dietary variety have been shown to increase voluntary feed intake in rodents (Rolls et al., 1983), pigs (Middelkoop et al., 2019), and dairy heifers (Meagher et al., 2017).

We noted no differences in bodyweight or BCS due to CP level, CP feeding pattern, or the interaction. In our study, the magnitude of dietary changes, length of dietary adaptation (24-d), number of cows, and schedule of BW measurements was likely insufficient to detect treatment differences in bodyweight. Liu et al. (2021) compared productive performance of Holsteins fed low (13%) and high (16%) CP, finding that low CP reduced gains of BW and empty body weight over 28- and 35-d periods in both peak and late lactation, although the low CP diet also reduced DMI in contrast to our study. Across our 112-d trial, linear effects for time showed that cows tended to lose a small amount of bodyweight (-9.4 kg; $P = 0.060$) but gained condition score (+0.06, $P < 0.001$; Supplemental Tables 2-3). Thus, when averaging across LP and HP conditions for both CP feeding patterns, conditions generally supported production and maintenance without excessive mobilization or accretion of body reserves. In agreement with the lack of CP feeding pattern effect in our trial, recent research showed no differences in BW and BCS in dairy cattle between oscillating and static CP feeding patterns in short-term experiments lasting 25-60 d (Kohler, 2016; Tebbe and Weiss, 2020; Rauch et al., 2021). Tebbe and Weiss (2020) observed no differences in empty body weight and urea space volume due to CP level (14.1 vs. 16.2 % CP) or CP feeding pattern (Tebbe and Weiss, 2020). Considering the importance of protein reserves in the homeorhetic metabolic changes associated with lactation (McCabe and Boerman, 2020), longer-term research is warranted to assess the effects of dietary protein and AA nutrition and CP feeding patterns in late lactation on body protein accumulation and subsequent lactation performance.

2.4.2 Milk Yield and Composition

Milk and component production in general was similar across treatments (Table 5). The lack of CP level effect on productive performance contrasted recent change-over (Gonzalez Ronquillo et al., 2021) and parallel (Barros et al., 2017) studies where dietary CP was replaced with primarily starch and NDF, respectively. When increasing CP from 11.8 to 16.2% CP across 4 treatments with late-lactation cows, Barros et al. (2017) observed positive linear and negative quadratic CP effects on component yields, where the yield response to additional dietary CP gradually declined. Comparing 14.4 to 16.2% CP, Barros et al. (2017) found no statistical difference in yields of milk or FPCM. When increasing from 11.0 to 17.0% CP for mid-lactation cows, Gonzalez Ronquillo et al. (2021) found positive linear and negative quadratic responses in milk and protein yields where the 15.0% CP treatment maximized yields. Stevens et al. (2021) reported similar productive performance for early lactation multiparous cows fed 15.5 or 17.5%

CP diets including supplemental RUP and rumen-protected amino acids. In our study, decreasing CP from 15.5 to 13.8% had no effects on production variables of economic importance.

CP feeding pattern had minimal effects on milk and component yields in our trial, which is mostly consistent with recent research. Tebbe and Weiss (2020) reported no differences in milk component yields when cows were fed in a 24-h oscillating CP pattern, however, they observed a significant reduction in milk protein concentration with oscillating versus static. Similarly, Kohler (2016) found milk component yields were similar for cows on oscillating CP feeding patterns (24-, 48- and 72-hr) versus static, except milk protein yield was reduced. Similar to our trial, Rauch et al. (2021) and Brown (2014) observed no differences in milk and component production with 48-h oscillating and static CP feeding patterns. In our trial, CP level and CP feeding pattern tended to interact to influence milk true protein concentration, which was numerically greater for cows fed OF-HP compared with other experimental conditions, although differences were economically inconsequential.

Although we found few differences in economically relevant milk variables, we observed meaningful differences in MUN that may suggest differences in N metabolism. Diets with HP caused significantly greater MUN (12.2 versus 9.0 mg/dL) and MUNY (4.62 vs. 3.44 g/d), which is consistent with previously reported values for diets with similar ingredient composition and CP level (Brito and Broderick, 2006; Olmos Colmenero and Broderick, 2006). We observed a tendency for lesser MUN with OF versus SF diets, which contrasts with previous literature where oscillating CP increased (Rauch et al., 2021) or tended to increase MUN (Tebbe and Weiss, 2020; Kohler, 2016). Differing CP feeding patterns (e.g., 24 vs. 48 h phase) and diets with different sites, rates, and extents of carbohydrate and protein degradation may affect ammonia absorption into blood, urea return to the gastrointestinal tract, and capture into ruminal microbial protein (Lapierre and Lobley, 2001). The reasons for differential MUN and MUNY responses to oscillating diets require further mechanistic investigation.

Importantly, our study used a change-over design, which may have dampened our ability to detect differences in certain production variables. Several meta-analyses (Huhtanen and Hetta, 2012; Zanton, 2016) and 1 prospective trial (Zanton, 2019) showed that most milk production variables responded rapidly-enough to dietary CP manipulation to be detected using a crossover design similar to our trial. However, Zanton (2019) observed carryover effects in milk fat and consequently milk energy output with a CP manipulation similar to our trial, suggesting that longer-term studies may be required to detect production responses in these variables. Additionally, our trial included multiparous cows, whereas recent research showed that long-term lower-CP feeding could negatively affect productive performance of primiparous cows (Reynolds et al., 2016). Finally, because LP did not limit productivity, further study is required to determine if the effects of CP feeding pattern differ with more severe CP deficiencies.

2.4.3 Milk Yield and Composition Over Time

Several production responses were affected by treatment by sampling day interactions (Table 5 and Supplemental Figures). These CP feeding pattern-related differences in milk yield translated to slight declines in milk component yields for SF over the sampling period, while OF component yields appeared steadier across the 4-d sampling. In contrast with other production variables where no temporal pattern was evident, MUN and MUNY showed a clear oscillation pattern in OF treatments while remaining constant across time in SF treatments (Figure 2). When oscillating diets were fed, MUN and MUNY rose gradually throughout the high-CP phase (d-25 to d-26) and declined before the beginning of low-CP feeding. The amplitude and timing of MUN and MUNY rise and fall was similar across LP and HP conditions. Considering the equivalence of SF-HP and OF-LP diets during the high-CP phase, and the equivalence of SF-LP and OF-HP diets during the low-CP phase, it is notable that MUN and MUNY in oscillating conditions fully-responded within 48-h (2 feedings) of the diet changes imposed in this study.

Table 6 shows the cosinor parameters amplitude and acrophase estimated for selected milk yield component variables. Figure 2 shows raw production data superimposed with cosinor least squares mean production over the 4-d sampling period for these variables. Acrophase parameters are shown for variables with significant amplitudes (Table 6). In general, acrophase estimates suggested component production peaked near the 2 milkings preceding the dietary transition from higher-CP to lower-CP. The amplitude parameter was non-significant for yields of milk and FPCM. For other variables, non-zero amplitudes indicated that a wave-like pattern with 96 h period could be detected after controlling for covariates. Amplitude estimates indicated that milk true protein yield increased and decreased very slightly (0.01 kg/milking) relative to the MESOR when OF-LP was fed, but no 96 h wave-like pattern was apparent across the intensive sampling period for OF-HP-fed cows. Milk true protein concentration increased slightly (0.02-0.03%) for both OF-LP and OF-HP fed cows following higher-CP-phase. In our trial, the lack of response in milk, FPCM, and protein yield to changes in oscillation phase may indicate that cows mobilized sufficient labile-N reserves to compensate for the transient dietary CP insufficiency, or instead that the lower-CP phases (12.2 and 13.8% CP for OF-LP and OF-HP treatments) provided adequate MP and AA supply to support similar production. This shows that regardless of dietary CP level, cows in our experiment sustained steady production of economically-relevant milk components despite regular dietary CP over- and under-sufficiency during oscillation phases.

In our OF-LP condition, acrophase estimates suggested the slight increase in milk true protein yield and milk N production peaked at the milking immediately before the diet change

(42.6-42.4 h). For both OF-LP and OF-HP, milk true protein concentration appeared to peak at the third of 4 milkings during the higher-CP oscillation phase (32.8-33.2 h), suggesting milk protein concentration rebounded more quickly than milk protein production after the resumption of higher-CP-phase feeding. Interestingly, Tebbe and Weiss (2020) reported increased milk and protein yields during the low-CP oscillation phase that suggested a delayed production response to dietary changes. In contrast, Rauch et al. (2021) showed a more immediate response where milk and component production gradually decreased during the low-CP phase with a nadir at the transition from low-CP to high-CP diets, then gradually increased during the high phase. Because several milk production variables rose and fell symmetrically with a peak near the oscillation phase transition in our trial, our results emphasize the importance of examining responses at the finest possible timescale (e.g., presenting results by milking rather than by period) to avoid obscuring meaningful within-period physiological changes when aggregating data across time.

Compared with other variables in our study, MUN and MUNY showed the largest and most immediate response to dietary changes, even after adaptation. The MUNY per milking was altered significantly across the duration of the oscillation phases (span of OF-LP = 0.43, OF-HP = 0.39 g), as was MUN (span of OF-LP = 2.21, OF-HP = 2.12 g). Based on the cosinor model, total milk N increased and decreased temporally by 2.34 g per milking for OF-LP, but no wave-like patterns matching the oscillation period were apparent in OF-HP, although these results did not differ from each other. Among variables with significant amplitude parameters, LP vs. HP contrasts indicated amplitudes were similar across CP levels. For MUNY and MUN, where the most prominent oscillation pattern was visible, acrophase estimates suggested a peak near the 3rd (OF-HP) or 4th (OF-LP) milking in the higher-CP phase. No differences between LP and HP amplitude and acrophase parameters were evident except with the MUN acrophase, which suggested that MUN concentration peaked later for LP than HP. Temporal patterns in group-average MUN have been proposed as an on-farm indicator of dietary CP adequacy (Powell et al., 2011) and limited evidence suggests that MUN may vary based on the adequacy of the absorbed AA profile (Appuhamy et al., 2011) in relation to requirements. Because MUN is strongly-correlated with urinary-N excretion, MUN-monitoring has the potential to decrease ammonia and nitrous oxide emissions (Burgos et al., 2007; Powell and Rotz, 2015), based on research with static CP diets. Our results support the assertion that dietary CP and MUN are positively related and that MUN can indicate minor (1.75% CP) and brief (24-48 hr) changes in dietary CP even when cows have been adapted to time-varying diets.

2.5 Conclusions

Results of our study suggested that dietary CP level did not affect production of milk or economically-relevant milk components in mid- to late-lactation cows, and instead HP contributed to greater MUN and MUNY and reduced NUE. Contrary to our hypothesis, the effects of 48-h oscillating CP feeding patterns on productive performance were consistent across CP levels. In our trial, CP feeding pattern did not appear to induce nutrient-sparing or production-enhancing effects, regardless of the CP level. Interestingly, we observed a tendency for lesser MUN with oscillating CP feeding pattern vs. static that contradicted previous studies. With the dietary changes in this study, MUN and MUNY fully-responded within 2 feedings and oscillated at a 36-40 h delay relative to dietary changes. Economically-relevant milk production variables such as milk fat and protein production showed no or minimal changes from milking-to-milking despite time-varying diet composition. In summary, the 48-h dietary oscillations imposed in our trial had minimal net effects on productive performance but altered urea-N metabolism as reflected by MUN, MUNY, and MPY/MUNY.

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2.8 Tables and Figures

Table 2.1. Ingredient composition of diets used in oscillating (OF) and static (SF) feeding patterns at low (LP) and high (HP) crude protein levels, ingredient DM as a percentage of diet DM.

	OF-LP Low Phase	OF-HP Low Phase; SF-LP	OF-LP High Phase; SF-HP	OF-HP High Phase
Corn silage	47.00	47.00	47.00	47.00
Alfalfa haylage	13.00	13.00	13.00	13.00
Ground corn (fine)	14.00	12.00	10.00	8.00
Soybean hulls	10.50	8.00	5.50	3.00
Solvent soybean meal	3.00	8.00	13.00	18.00
Expeller soybean meal[1]	5.00	4.50	4.00	3.50
Molasses	2.70	2.70	2.70	2.70
Animal/plant fat supplement[2]	2.00	2.00	2.00	2.00
Calcium carbonate	0.80	0.80	0.80	0.80
Sodium bicarbonate	0.30	0.30	0.30	0.30
Vitamin-mineral premix[3]	0.10	0.10	0.10	0.10
Potassium and magnesium sulfate[4]	0.90	0.90	0.90	0.90
Magnesium oxide[5]	0.30	0.30	0.30	0.30
Mono- and dicalcium phosphate[6]	0.40	0.40	0.40	0.40

1. SoyPlus®, Landus Cooperative, Ames, IA
2. Energy Booster 100®, Milk Specialties Global, Eden Prairie, MN
3. The vitamin-mineral premix was commercially formulated to contain: 0.35% Ca, 82.12% NaCl, 0.09% S, 64 mg/kg Co, 4,831 mg/kg Cu, 381.6 mg/kg I, 1472 mg/kg Fe, 14,250 mg/kg Mn, 76 mg/kg Se, 20,520 mg/kg Zn, 391,739 IU/kg vitamin A, 78,348 IU/kg vitamin D, 1,958,693 IU/kg added vitamin E, 39.1 mg/kg biotin, 3.79 g/kg monensin, 0.68 g/kg diflubenzuron.
4. Commercially formulated for: 18% K, 11% Mg, 22% S.
5. Commercially formulated to contain: 56% Mg
6. Commercially formulated to contain a minimum of: 18.5% P, 19.0% Ca

Table 2.2. Nutrient composition of composite samples of each diet used in oscillating (OF) and static (SF) feeding patterns at low (LP) and high (HP) crude protein levels.[1]

Nutrient[2]	OF-LP Low Phase (n = 4)	OF-HP Low Phase; SF-LP (n = 4)	OF-LP High Phase; SF-HP (n = 4)	OF-HP High Phase (n = 4)
DM	47.00 (1.71)	46.51 (1.83)	46.75 (1.47)	46.36 (1.23)
OM	95.85 (0.24)	95.64 (0.60)	95.71 (0.39)	95.46 (0.27)
CP	12.20 (0.27)	13.78 (0.62)	15.47 (0.79)	17.26 (0.93)
ADF	20.25 (0.93)	19.53 (1.30)	18.25 (1.57)	17.64 (2.06)
ADFom[3]	19.87 (1.03)	18.94 (1.21)	17.69 (1.48)	16.91 (2.08)
aNDF[4]	30.40 (1.43)	28.45 (1.29)	26.74 (2.02)	26.29 (1.79)
aNDFom[5]	29.96 (1.50)	27.89 (1.16)	26.12 (1.92)	25.54 (1.74)
ADICP[6]	0.69 (0.11)	0.74 (0.35)	0.64 (0.05)	0.63 (0.09)
NDICP[7]	1.31 (0.02)	1.29 (0.07)	1.21 (0.07)	1.16 (0.03)
WSC[8]	4.46 (0.38)	4.91 (1.20)	5.76 (0.53)	5.34 (1.42)
Starch	27.09 (3.29)	25.21 (2.04)	25.54 (2.72)	24.67 (3.01)
Lignin	3.06 (0.39)	2.88 (0.42)	3.03 (0.38)	3.20 (0.42)
EE[9]	5.45 (0.26)	5.12 (0.05)	5.13 (0.21)	5.13 (0.15)

1. Mean (standard deviation).
2. All nutrient composition is expressed as a % of DM except for DM, which is a percentage of the diet as-fed.
3. ADFom = acid detergent fiber corrected for ash content
4. aNDF = neutral detergent fiber using amylase and sodium sulfite
5. aNDFom = neutral detergent fiber corrected for ash content, using amylase and sodium sulfite
6. ADICP = acid detergent insoluble crude protein
7. NDICP = neutral detergent insoluble crude protein
8. WSC = water-soluble carbohydrates
9. EE = ether extract

Table 2.3. Nutrient composition of composite forage samples.

Nutrient[1]	Corn Silage (n = 4)	Alfalfa Haylage (n = 4)
DM (% as-is)	35.84 (1.68)	35.45 (3.71)
OM	99.86 (0.82)	93.54 (1.41)
CP	6.27 (0.66)	20.30 (1.12)
ADF	19.13 (0.94)	28.13 (3.02)
ADFom[2]	18.23 (1.17)	27.59 (3.34)
aNDF[3]	30.87 (1.18)	34.45 (2.56)
aNDFom[4]	30.14 (1.20)	33.53 (2.45)
ADICP[5]	0.65 (0.03)	1.31 (0.08)
NDICP[6]	0.90 (0.11)	1.83 (0.15)
WSC[7]	1.88 (0.38)	2.18 (0.25)
Starch	45.15 (3.68)	2.32 (2.04)
Lignin	2.72 (0.17)	7.06 (0.86)
EE[8]	3.26 (0.65)	4.83 (0.32)

1. All nutrient composition is expressed as the mean and standard deviation in % of DM except when otherwise specified
2. ADFom = acid detergent fiber corrected for ash content
3. aNDF = neutral detergent fiber using amylase and sodium sulfite
4. aNDFom = neutral detergent fiber corrected for ash content, using amylase and sodium sulfite
5. ADICP = acid detergent insoluble crude protein
6. NDICP = neutral detergent insoluble crude protein
7. WSC = water-soluble carbohydrates
8. EE = ether extract

Table 2.4. Predicted supplies and requirements of net energy of lactation[1] and protein fractions for n = 16 cows fed combinations of crude protein (CP): low protein (LP = 13.8% CP) or high protein (HP = 15.5% CP), with oscillating (OF, ±1.8% CP at 48-h intervals) or static (SF) feeding patterns.

Nutrient	OF-LP Low Phase	OF-HP Low Phase; SF-LP	OF-LP High Phase; SF-HP	OF-HP High Phase
NE_L, Mcal/d				
Supply	45.5	45.6	45.6	45.6
Requirement	41.5	41.5	41.5	41.5
Balance	4.0	4.1	4.1	4.1
MP, g/d				
Supply	1880	2113	2343	2569
Requirement	2260	2256	2251	2247
Balance	-381	-143	92	322
MP from Microbes	1010	1126	1239	1347
MP from RUP	869	987	1104	1222

1. Predicted with NASEM (2021) dairy-8 software using measured DMI, milk yield and composition, available feed composition, BW, DIM, and days in gestation for the study.

Table 2.5. Milk and production performance across 4-d sampling for n = 16 cows fed combinations of low protein (LP = 13.8% of DM) or high protein (HP = 15.5% of DM), where diets alternated ±1.8% CP every 2-d (oscillating; OF) or remained static (SF). Results show least squares means and contrasts for dietary CP level (P_l, where *l* = LP, HP), CP feeding pattern (F_m, where *m* = OF, SF), the interaction term between CP level and CP feeding pattern (F:P), day (D_n, where *n* = 25, 26, 27, 28), and interactions of day with treatments (F:D and F:P:D).

Crude Protein Level	LP		HP			Contrasts (*P*)					
Feeding Pattern	OF	SF	OF	SF	SEM	P	F	F:P	D	F:D	F:P:D
DMI, kg/d	24.9	24.8	25.4	24.8	0.7	0.60	0.42	0.56	0.07	0.31	0.12
BW, kg	661	665	671	667	16	0.28	0.95	0.44			
BCS	3.11	3.14	3.17	3.13	0.07	0.29	0.64	0.30			
Milk yield, kg/d	38.5	38.5	38.9	37.9	1.3	0.82	0.38	0.39	0.02	<0.001	0.32
FPCM[1], kg/d	37.1	37.6	38.1	37.4	1.1	0.60	0.90	0.38	<0.001	0.00	0.05
True protein, kg/d	1.11	1.12	1.14	1.10	0.04	0.70	0.45	0.21	0.09	<0.001	0.28
Fat, kg/d	1.53	1.57	1.58	1.57	0.05	0.48	0.70	0.56	<0.001	0.06	0.08
Lactose, kg/d	1.80	1.80	1.82	1.77	0.07	0.75	0.28	0.40	0.04	0.00	0.28
MUNY[2], g/d	3.36	3.51	4.56	4.68	0.15	<0.001	0.17	0.91	<0.001	<0.001	0.50
Milk energy, Mcal/d	27.4	27.8	28.1	27.6	0.8	0.61	0.87	0.39	<0.001	0.002	0.05
Milk N, g/d	175	177	181	174	6	0.58	0.47	0.21	0.11	<0.001	0.28
Milk composition											
True protein, %	2.88	2.91	2.93	2.90	0.04	0.24	0.79	0.09	0.05	<0.001	0.94
Fat, %	4.02	4.10	4.13	4.17	0.12	0.29	0.50	0.83	0.02	0.65	0.45
Lactose, %	4.67	4.66	4.66	4.66	0.04	0.69	0.52	0.80	0.82	0.23	0.62
MUN, mg/dL	8.81	9.19	11.98	12.47	0.30	<0.001	0.06	0.79	<0.001	<0.001	0.32
Milk energy, Mcal/kg	0.72	0.72	0.73	0.73	0.01	0.24	0.53	0.70	0.02	0.72	0.43

1. FPCM = fat-protein-corrected milk
2. MUNY = MUN yield.

Table 2.6. Results of single cosinor models for variables with a significant time by feeding pattern interaction (n = 248 observations from n = 16 cows).[1]

	Amplitude[2]					Acrophase[3], h				
	LP		HP		LP vs. HP	LP		HP		LP vs. HP
Item	Est.	CI	Est.	CI	*P*	Est.	CI	Est.	CI	*P*
Milk yield (kg/milking)	0.30	(-0.03, 0.66)	0.06	(-0.33, 0.19)						
FPCM[4], kg/milking	0.21	(-0.23, 0.52)	0.28	(-0.31, 0.69)						
True protein, kg/milking	0.01	(0.00, 0.02)	0.00	(-0.01, 0.01)	0.21	42.6	(28.9, 56.1)			
Lactose, kg/milking	0.01	(0.00, 0.03)	0.00	(-0.02, 0.01)						
MUNY[5], g/milking	0.43	(0.35, 0.51)	0.39	(0.30, 0.48)	0.58	40.3	(37.7, 42.9)	37.5	(35.0, 40.2)	0.15
Milk energy, Mcal/ milking	0.15	(-0.18, 0.37)	0.21	(-0.22, 0.52)						
Milk N, g/milking	2.34	(0.79, 4.11)	0.75	(-0.80, 1.93)	0.18	42.4	(30.0, 54.6)			
Milk composition										
True protein, %	0.02	(0.00, 0.05)	0.03	(0.01, 0.05)	0.77	32.8	(25.0, 41.1)	33.2	(26.3, 40.8)	0.95
MUN, mg/dL	2.21	(1.87, 2.59)	2.12	(1.72, 2.54)	0.77	40.0	(37.7, 42.4)	36.3	(34.3, 38.5)	<0.001

1. LP: Low Protein, HP, High Protein; Est.: parameter estimate; CI: confidence interval. The LP vs. HP contrast is only reported when an amplitude differed significantly from zero.
2. Amplitude is in the units of the analyte and represents half of the predicted range from nadir to peak.
3. Acrophase is the time of the peak expressed as h since the first feeding of the high-phase diet. It is reported only when an amplitude differed significantly from zero.
4. FPCM = fat-protein-corrected milk
5. MUNY = MUN yield

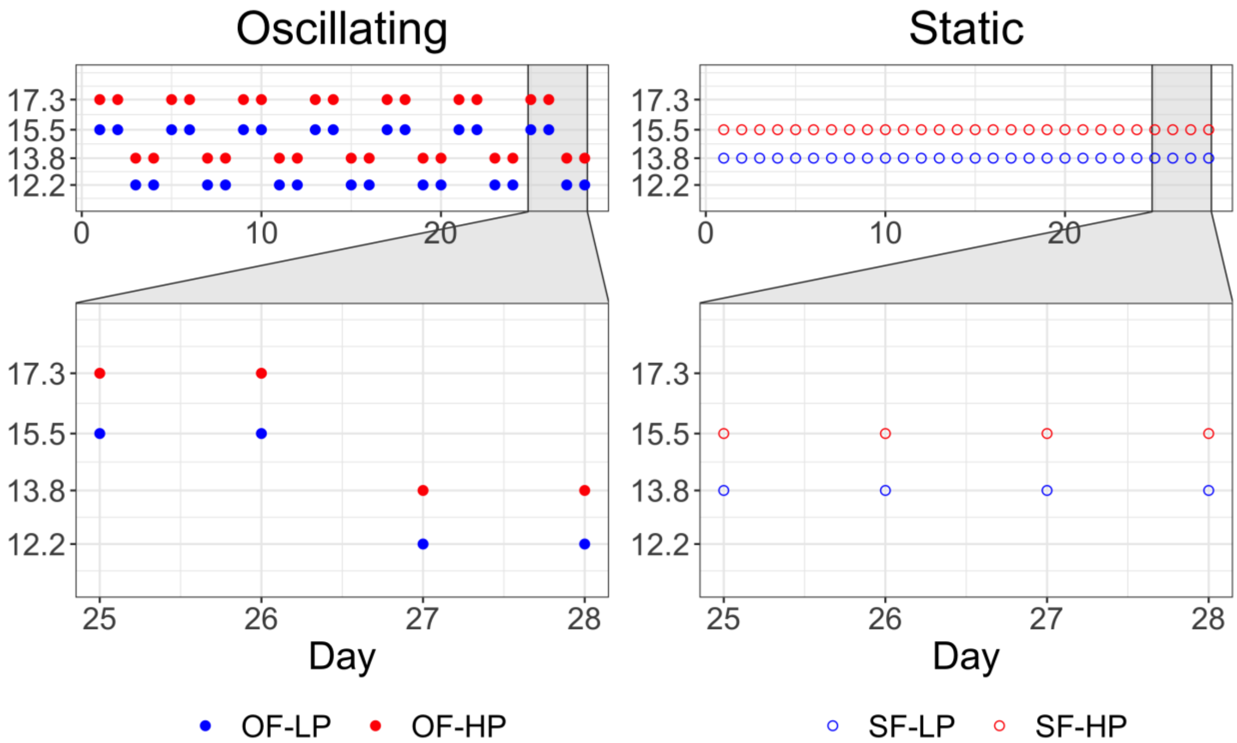


Figure 2.1. Dietary crude protein concentration (CP, % of dry matter) at once daily feedings across a 28-d experimental period for 2x2 factorial combinations of CP feeding pattern and CP level: oscillating low protein (OF-LP), oscillating high protein (OF-HP), static low protein (SF-LP) static high protein (SF-HP). The 4-d intensive sampling frame (d-25 to 28) is highlighted.

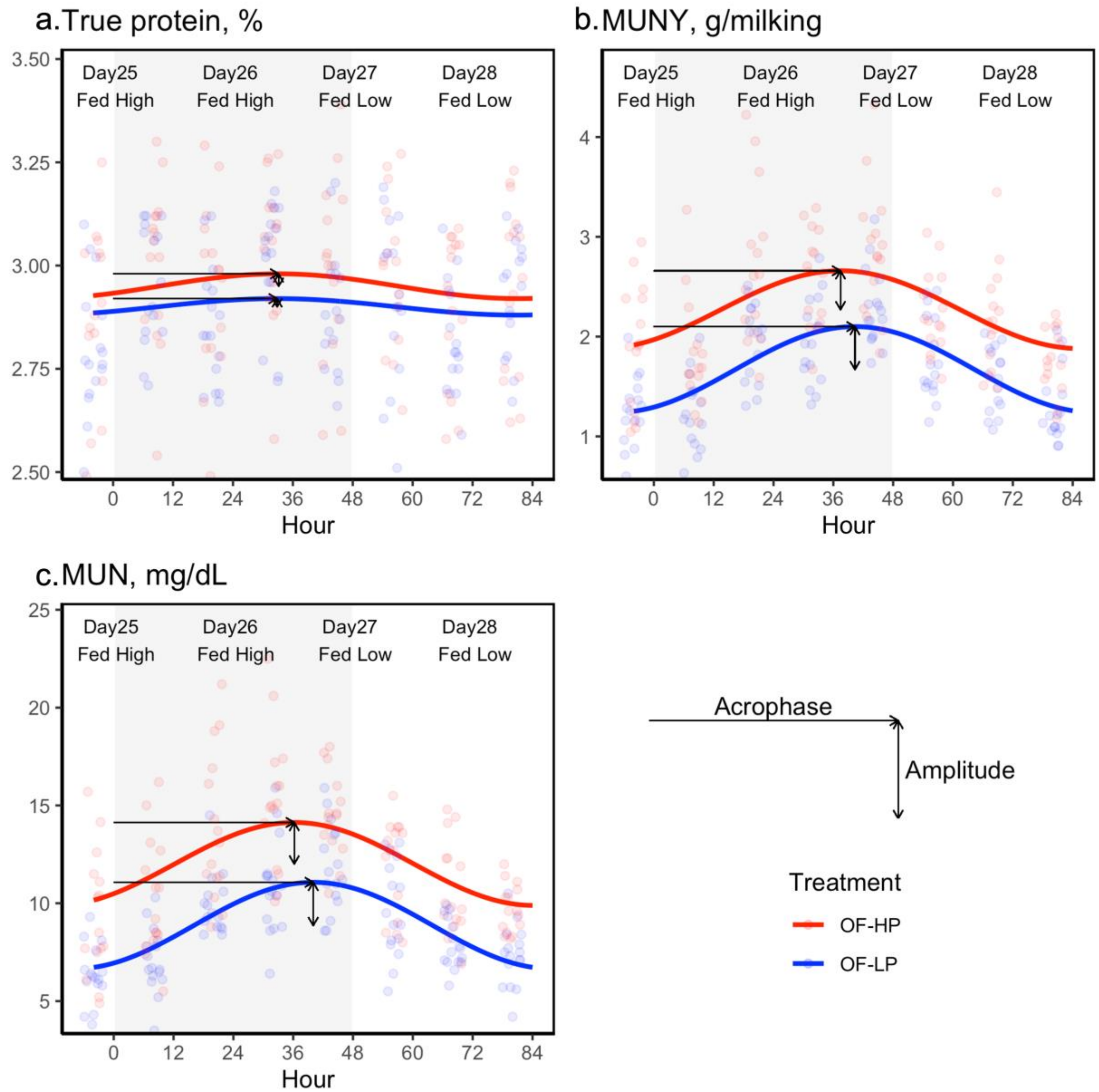
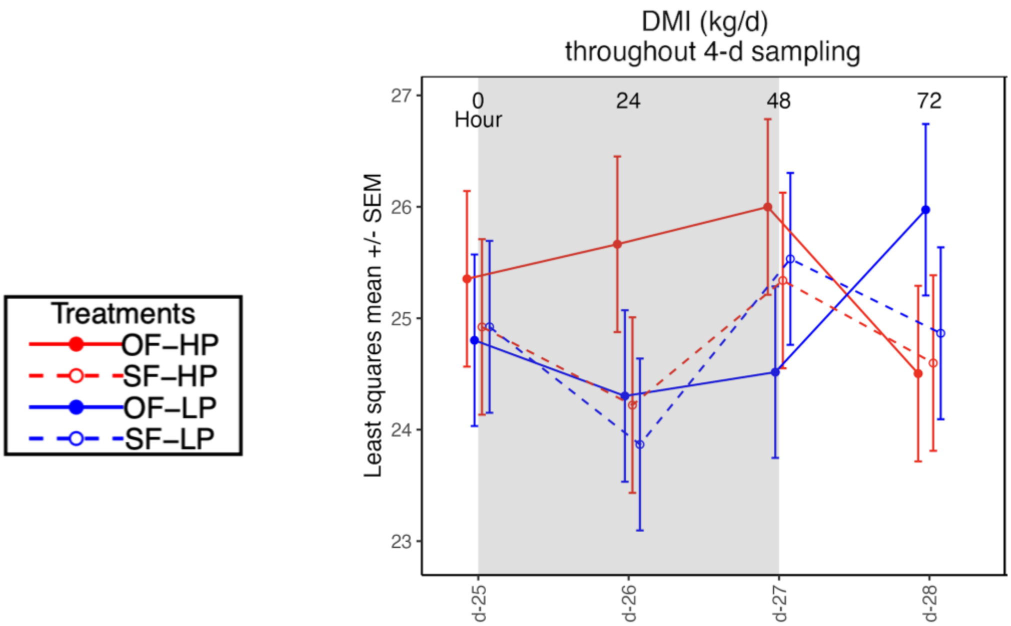


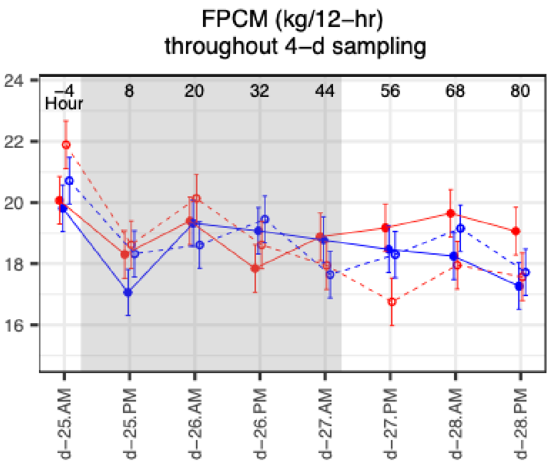
Figure 2.2. Temporal patterns in (a) milk true protein concentration (%), (b) MUN yield (MUNY, g/d), and (c) MUN concentration (MUN, mg/dL) implied by mixed effect cosinor models on a subset of observations (n = 248) under conditions of oscillating high protein (OF-HP, 15.5±1.8% crude protein), and oscillating low protein (OF-LP, 13.8±1.8% crude protein). Due to the 48-h interval between diet changes, cosinor models assumed a 96 h period centered (time = 0 h) at the time of the first higher-CP phase feeding for OF. The y-axis range was set based on the range in raw observations. A grey rectangle shows the higher-CP phase in OF. Points show raw data from twice-daily milkings d-25 a.m. (-4 h) to d-28 p.m. (84 h).

2.9 Appendix

Supplemental Figures. Milk and component yields and component concentrations per milking for lactating Holsteins (n = 17) fed combinations of crude protein (CP) level and CP feeding pattern. This cross-over experiment consisted of four 28-d periods, each ending with 4-d sample collection at twice daily milkings and once daily feedings. Low protein (LP) centered at 13.8% CP of DM and high protein (HP) centered at 15.5% CP. Feeding patterns consisted of an oscillating pattern (OF) where CP% alternated ±1.8% CP at 48-hr intervals and a static (SF) pattern where CP was constant across time. Note: FPCM = fat-protein-corrected milk; MUNY = milk urea nitrogen. Milk N (g) was calculated as (g MUNY*0.46) + (g true protein/6.38). FPCM was determined as [(1.226 × milk fat concentration) + (0.0776 × milk true protein concentration) + 0.2534)], weighted by the milk yield (kg). Milk net energy was calculated per the NRC (2001) equation 2-15, NEl (Mcal/kg) = [(0.0929 × milk fat concentration) + (0.0547 × milk CP concentration) + (0.0395 × lactose concentration)].

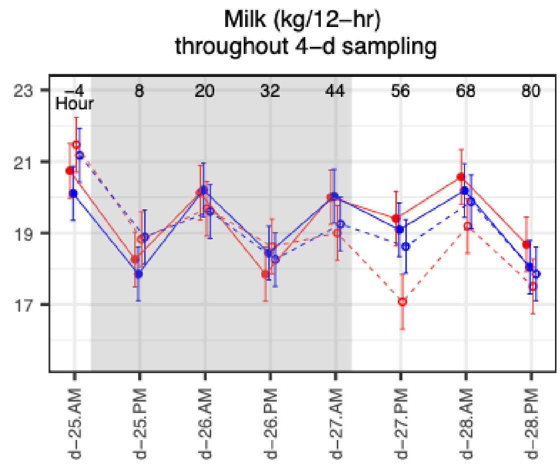


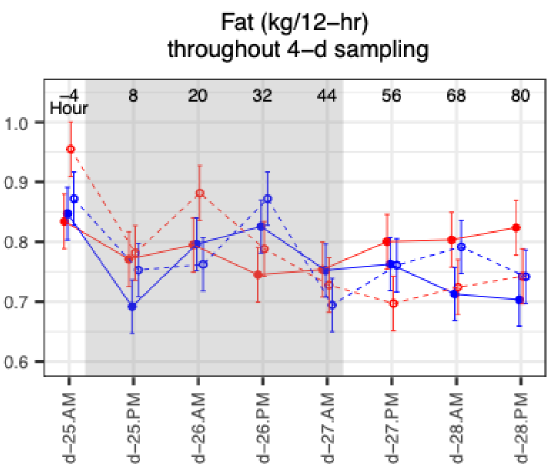
Supplemental Figures (cont.)



	P–value
D	<0.001
D:F	0.002
D:F:P	0.050

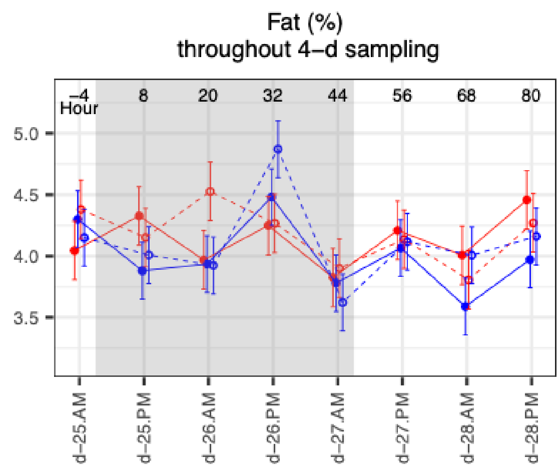
	P–value
D	0.024
D:F	<0.001
D:F:P	0.322

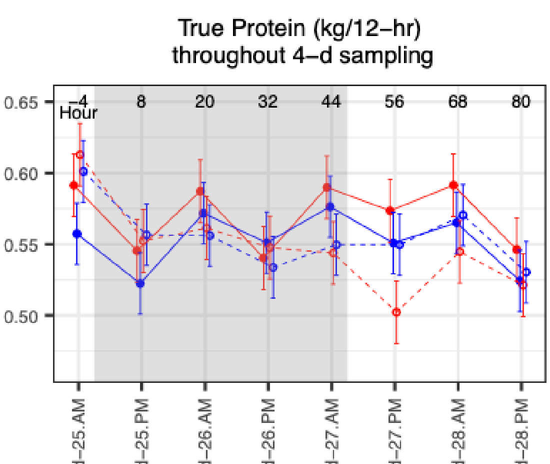




	P–value
D	<0.001
D:F	0.056
D:F:P	0.083

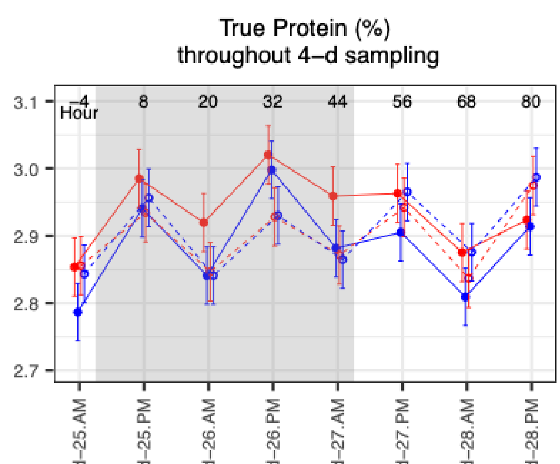
	P–value
D	0.020
D:F	0.652
D:F:P	0.452



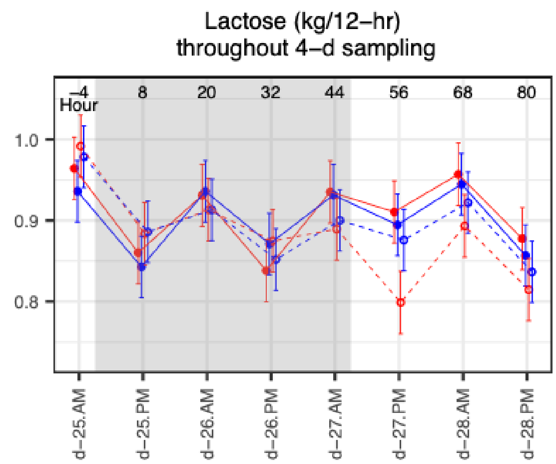


	P–value
D	0.094
D:F	<0.001
D:F:P	0.277

	P–value
D	0.048
D:F	<0.001
D:F:P	0.935

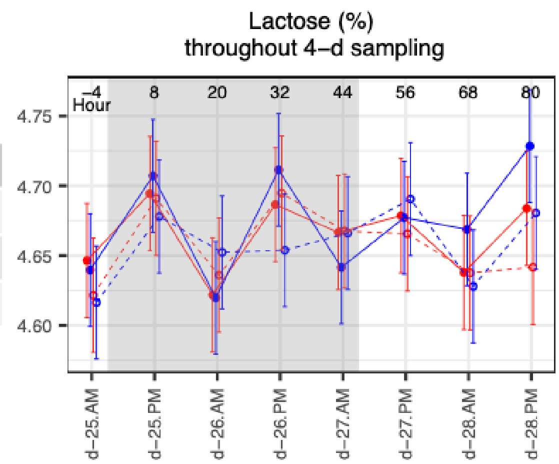


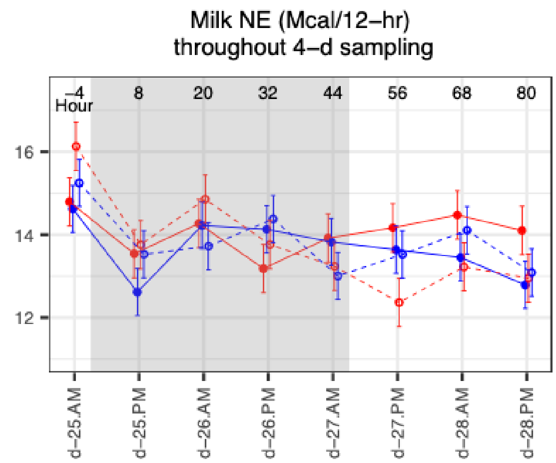
Supplemental Figures (cont.)



	P–value
D	0.039
D:F	0.001
D:F:P	0.283

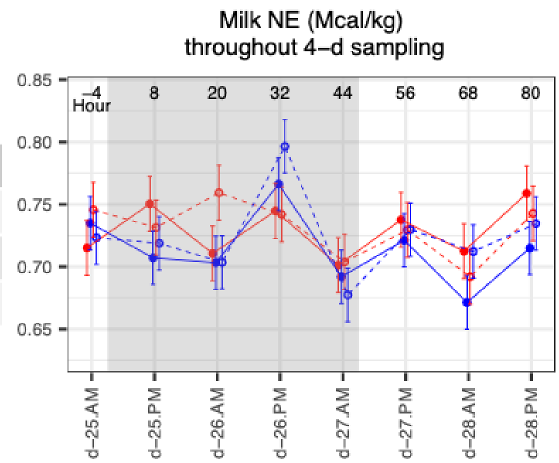
	P–value
D	0.822
D:F	0.227
D:F:P	0.623

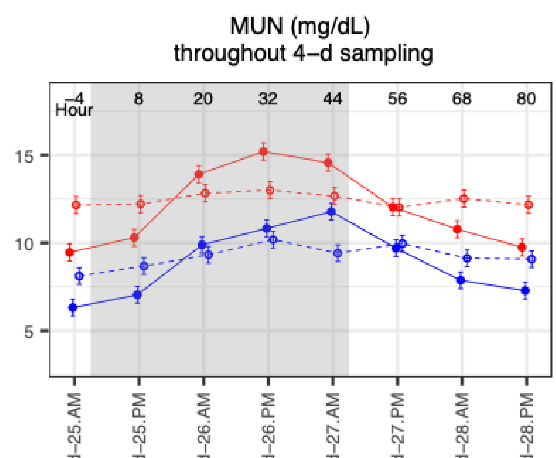




	P–value
D	<0.001
D:F	0.002
D:F:P	0.046

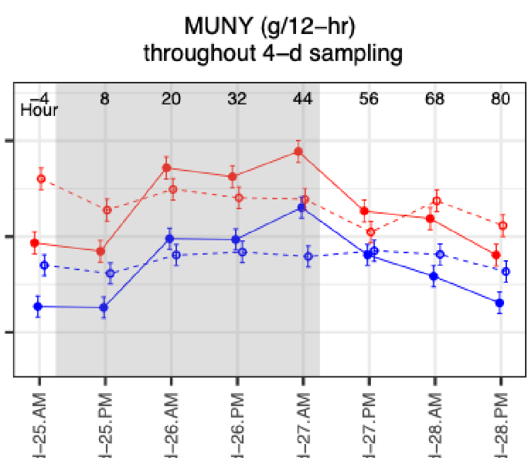
	P–value
D	0.017
D:F	0.716
D:F:P	0.426





	P–value
D	<0.001
D:F	<0.001
D:F:P	0.321

	P–value
D	<0.001
D:F	<0.001
D:F:P	0.501



Supplemental Table 2.1 Dry matter intake regressed on experimental factors using a linear mixed model with fixed effects for cannulation status (S_j, where j = cannulated, non-cannulated), experimental period (E_k, where *k* = 1, 2, 3, 4), dietary CP level (P_l, where *l* = LP, HP), CP feeding pattern (F_m, where *m* = OF, SF), the interaction term between CP level and CP feeding pattern, and a fixed effect and all possible interactions between day (D_n, where *n* = 25, 26, 27, 28) with treatments. We included random intercepts for cow and cow:period and a random error term (ϵ_{ijklm}; n = 248).

Fixed Effects	df	df	*F*	*P*
S	1	15.35	0.016	0.900
E	3	40.28	26.702	<0.001
D	3	174.00	2.434	0.067
P	1	40.06	0.284	0.597
F	1	40.74	0.676	0.416
D:P	3	174.00	3.076	0.029
D:F	3	174.00	1.194	0.314
P:F	1	40.05	0.355	0.555
D:P:F	3	174.00	1.969	0.120

Random Effects[1]	
σ^2	2.98
$\tau_{00\ period:cow}$	2.02
$\tau_{00\ cow}$	4.67
ICC	0.69
N_{period}	4
N_{cow}	17
Observations	248
Marginal R^2	0.298
Conditional R^2	0.784

[1]The σ^2, $\tau_{00\ period:cow}$ and $\tau_{00\ cow}$ represent the within-cow:period, between-cow:period, and between-cow variances, respectively. ICC shows the intraclass-correlation coefficient for the random effects.

Supplemental Table 2.2. Bodyweight regressed on experimental factors using a linear mixed model with fixed effects for cannulation status (S_j, where j = cannulated, non-cannulated), experimental period (E_k, continuous at 28-d intervals), dietary CP level (P_l, where *l* = LP, HP), CP feeding pattern (F_m, where *m* = OF, SF), and the interaction term between CP level and CP feeding pattern. We included a random intercept for and a random error term (ϵ_{ijklm}; n = 64).

Fixed Effects	df	df	*F*	*P*
S	1	15.05	0.272	0.610
E (linear)	1	44.15	3.728	0.060
P	1	43.18	0.330	0.569
F	1	44.38	0.000	0.984
P:F	1	43.18	0.162	0.689

Random Effects[1]	
σ^2	1852
$\tau_{00\ cow}$	3296
ICC	0.64
N_{cow}	17
Observations	64
Marginal R^2	0.036
Conditional R^2	0.653

[1]The σ^2 and τ_{00} represent the within-cow and between-cow variances, respectively. ICC shows the intraclass-correlation coefficient for the random effect of cow.

Supplemental Table 2.3. Body condition score regressed on experimental factors using a linear mixed model with fixed effects for cannulation status (S_j, where j = cannulated, non-cannulated), experimental period (E_k, continuous at 28-d intervals), dietary CP level (P_l, where *l* = LP, HP), CP feeding pattern (F_m, where *m* = OF, SF), and the interaction term between CP level and CP feeding pattern. We included a random intercept for and a random error term (ϵ_{ijklm}; n = 64).

Fixed Effects	df	df	*F*	*P*
S	1	14.875	0.125	0.728
E (linear)	1	43.437	17.725	<0.001
P	1	42.929	0.644	0.427
F	1	43.557	0.068	0.796
P:F	1	42.929	1.115	0.297

Random Effects[1]	
σ^2	0.02
$\tau_{00\ cow}$	0.06
ICC	0.81
N_{cow}	17
Observations	64
Marginal R^2	0.064
Conditional R^2	0.822

[1]The σ^2 and τ_{00} represent the within-cow and between-cow variances, respectively. ICC shows the intraclass-correlation coefficient for the random effect of cow.

CHAPTER 3. LEVEL AND PATTERN OF CRUDE PROTEIN FEEDING: EFFECTS ON RUMEN FERMENTATION, NITROGEN BALANCE, NUTRIENT DIGESTIBILITY, AND GREENHOUSE GAS EMISSIONS

Citation:

Erickson, M.G., Zanton, G.I., and M.A. Wattiaux (2023, In preparation). Level and pattern of crude protein feeding: effects on rumen fermentation, nitrogen balance, nutrient digestibility, and greenhouse gas emissions.

3.1 Abstract

Reducing dietary CP is a well-established means to improve nitrogen use efficiency. Yet few studies have considered if transient restrictions in dietary CP could reduce the environmental footprint of late lactation cows. We hypothesized that the effects of CP feeding pattern would be amplified at lower dietary CP. We tested CP levels below and near predicted requirements (LP, 13.8%; HP, 15.5%) fed in two patterns: where diets alternated ±1.8% crude protein (CP) every 2-d (oscillating; OF) or remained static (SF). Our study used a 2x2 factorial design with 16 mid- to late-lactation Holsteins (M = 128, SD = 12 DIM), divided into rumen-cannulated (n = 8) and non-cannulated subsets (n = 8). For each 28-d experimental period, we recorded feed intake and milk production and took samples of orts (1x/d) and milk (2x/d) for 4-d. For the cannulated subset, we measured and sampled from the total mass of feces and urine production and collected plasma 2x/d across 4-d. For the non-cannulated subset, we sampled gas emissions 3x/d for 4-d. For each subset, we fit linear mixed models with fixed effects for CP level, CP feeding pattern, and period and a random effect for cow. For selected body urea-N pools, we conducted time series analysis. Contrary to our hypothesis, we found no evidence that dietary CP level and CP feeding pattern interacted to influence nitrogen balance, nutrient digestibility, or gas emissions. Results showed HP maintained milk N but increased manure N, reducing nitrogen use efficiency relative to LP. For OF, urea-N in urine and plasma peaked 46-52 hr after the first higher-CP phase feeding. Nutrient digestibility and gas emissions were similar across treatments, except CO_2 production was greater for OF-HP. In summary, measured variables were minimally affected by dietary CP alternating ±1.8% every 48-h, even when average dietary CP was fed below predicted requirements (LP). Although our findings suggest that mid- to late-lactation cows are resilient to oscillation in dietary-CP, oscillating CP neither reduced the environmental

footprint by improving nutrient use efficiencies nor reduced the potential for direct and indirect greenhouse gas emissions.

3.2 Introduction

Efforts to optimize lactation performance while managing environmental impacts of N have centered on reducing dietary crude protein (CP) while supplying adequate amino acids (AA), energy, and other nutrients to support milk protein synthesis. Perhaps the most well-established method to improve N efficiency in lactating cattle is the reduction of dietary CP (Dijkstra et al., 2013b). Reducing dietary CP has been shown to enhance urea-N recycling to the gastrointestinal tract (GIT), reduce renal urea-N clearance, and improve postabsorptive N efficiencies by altering the AA affinities of various tissues including those of the mammary gland (Lapierre and Lobley, 2001; Rius et al., 2010; Sinclair et al., 2014). Additionally, research showed a close linear relationship between dietary CP intake and excretion of urinary urea-N (UUN), which indicates that dietary CP is an important contributor to the amount of volatile N in manure (Powell et al., 2011). Although extensive research has evaluated N balance associated with different dietary CP levels given certain cow characteristics, most studies assessed responses after adaptation to diets formulated for constant composition over time. It remains unclear if the N-sparing effects observed with long-term dietary CP reduction could be achieved with transient restrictions in dietary CP intake, for example, by alternating dietary CP over time in an oscillating pattern.

Sheep and beef cattle fed oscillating CP levels maintained performance and sometimes retained a greater proportion of dietary N relative to control animals fed CP with a static pattern (Ludden et al., 2003; Schauer et al., 2010). Limited research on mid- to late-lactation dairy cattle showed that feeding oscillating CP ±1.5 to 3.0% of DM at 24- to 48-hr intervals had minimal effects on productive performance (Kohler, 2016; Tebbe and Weiss, 2020; Rauch et al., 2021a), inconsistent negative effects on N use efficiency, and inconsistent positive effects on digestibility of CP and other nutrients (Brown, 2014; Kohler, 2016; Tebbe and Weiss, 2020; Rauch et al., 2021a). These studies used a variety of different diets, ranges of CP oscillation, nutrients substituted for CP, and time intervals for oscillation, which limits the comparability of results among studies. Several notable findings have contributed to mechanistic understanding of oscillating diets. Tebbe and Weiss (2020) showed no differences between oscillating and static-fed cows in body weight or composition, and in plasma concentrations of glucose, insulin, and most AA. Kohler (2016) found greater apparent ruminal DM and OM digestion and a lesser amount of N passage to the omasal canal for cows fed oscillating CP patterns. However, it remains unclear if the effects of oscillating CP depend on the average level of dietary CP, i.e., if oscillating CP is more effective at lower dietary CP. Additionally, the effects of CP level and CP feeding pattern on greenhouse gas (GHG) production have not been described. Therefore, our objective was to evaluate the effects of dietary CP oscillation on ruminal parameters, nutrient digestibility, N balance, and GHG emissions. We hypothesized that oscillating dietary CP would enhance digestibility, reduce N excretion in manure, and increase methane emission of mid- to late-lactation cows when the average dietary CP was below predicted requirements, but not when CP was fed near predicted requirements.

3.3 Materials and Methods

This study was conducted at the University of Wisconsin—Madison Dairy Cattle Center from April to August 2021. All procedures involving animals were approved by the University of Wisconsin–Madison Institutional Animal Care and Use Committee (protocol #A006439).

3.3.1 Animals and Experimental Design

We used 16 multiparous, mid- to late-lactation Holstein cows (M = 128, SD = 12 DIM when the experiment began). Cows were divided into two subsets: non-cannulated (n = 8) and cannulated (n = 8; 10 cm ruminal cannula, Bar Diamond Inc., Parma, ID). Milk production, BW, BCS, and DMI were recorded for all cows and used to calculate N and feed efficiency metrics. Additional details on productivity are described in a separate manuscript (Erickson et al., 2023). The cannulated subset of cows was used for total urine and feces collection and plasma sampling. Due to GHG emission headbox procedures (described below) and possible gas escape through the rumen cannula, only the non-cannulated subset was used for GHG emission measurements. Within each subset, we assigned cows to four treatment sequences in a Latin Rectangle arrangement. Treatments constituted a 2x2 factorial arrangement with two levels of CP (LP = 13.8, HP = 15.5% CP of DM) and two CP feeding patterns (OF = oscillating dietary CP ± 1.8% of DM with diet changes at 48 h intervals, SF = static dietary CP). Each 28-d experimental period had an adaptation and GHG equipment re-training period (d 1-14), a GHG measurement period (d 14-21 for the non-cannulated cows), and a 4-d intensive sampling period (d 25-28; GreenFeed, C-Lock Inc, Rapid City, SD). Throughout the experiment, cows were housed in individual tie stalls with rubber mats. Stalls were bedded with wood shavings except during total fecal and urine collection. Cows were milked twice daily (0400 and 1600 h) and fed a TMR once daily (0800 h) aiming for a 5% refusal rate. Feed was pushed toward cows in the bunk once daily (~1800 h). Cows had *ad libitum* access to automatic waterers. The ambient temperature was controlled with an evaporative tunnel ventilation system in the barn.

3.3.2 Dietary Treatments

Full ingredient and nutrient composition of diets is available in a separate manuscript (Erickson et al., 2023). Each OF CP feeding pattern alternated between 2 diets (OF-LP 12.2-15.5%, OF-HP 13.8-17.3% CP) every 48 h throughout the experimental period such that mean diet composition equaled that of corresponding SF treatments. Each SF treatment consisted of a single diet fed throughout the experimental period (SF-LP, 13.8%; SF-HP, 15.5% CP). All diets were delivered as a TMR and had a constant 60:40 forage-to-concentrate ratio (DM basis) with dietary differences implemented using 4 different concentrate formulations. In the concentrate formulations, soybean hulls, ground corn, and expeller soybean meal were exchanged with solvent soybean meal to target constant dietary NDF to starch and rumen-degradable protein to CP ratios.

3.3.3 Measurements, Sampling, Laboratory Analysis, and Calculations

Unless otherwise stated, laboratory analysis occurred at the USDA Dairy Forage Research Center in Madison, WI.

Milk, Feed, Orts

Procedures for sampling of milk, TMR, forages, and orts are detailed in a separate manuscript (Erickson et al., 2023). In brief, milk weights were measured using the parlor system and recorded on paper by farm staff. Milk samples were taken via automatic samplers, preserved with bronopol tablets, and refrigerated until shipment for analysis. Milk samples were transported to a commercial laboratory for spectrometric analysis (Foss FT6000; Foss Electric, Hillerød, Denmark; AgSource Laboratories, Verona, WI). Procedures for milk component calculations, computation of fat- and protein-corrected milk, and for the aggregation of DMI, milk, BW, and BCS data are presented in a companion manuscript (Erickson et al., 2023). Milk N was calculated by the amounts (g) of milk true protein N and milk urea N (MUN), using N conversion factors of 6.38 and 2.17, respectively. We took daily samples of TMRs (n = 4), forages (n = 2), and orts (n = 8) from d-25 to d-28 of each experimental period. Compositing procedures for feeds and orts are detailed in a separate manuscript (Erickson et al., 2023). Feed and orts samples were dried at 105°C for 24 h to determine DM. The NDF procedure used a neutral detergent solution with amylase and sodium sulfite (method 2002.04.2005; Mertens, 2002). Both NDF and acid detergent fiber (ADF) residues were ashed at 600°C for 2 h to determine NDFom and ADFom (method 973.18, AOAC International, 1996). Indigestible NDF (iNDFom) was determined based on intraruminal incubation of F57 polyester filter bags (25 micron porosity, 5x5 cm, 500 mg sample) for 240 h using 2 cows on a diet similar to experimental diets (major ingredients: alfalfa haylage, corn silage, corn grain).

BW and BCS

Procedures for measuring, validating, and aggregating body weight and scoring body condition are detailed in a companion manuscript (Erickson et al., 2023). In brief, body weights were recorded prior to feeding and immediately after the 0400 milking for four days per experimental period. Three raters scored body condition in 0.25 increments on a 1 to 5 scale on d 23 to d 28 of each experimental period.

Rumen fluid

Rumen fluid was sampled with a metal probe *per cannula* at 0600, 0800, 1000, and 1900 h from d 25 to d 28 of each period. The pH of rumen fluid was analyzed cow-side within 20 minutes of sample collection using a portable pH meter (WTW 3110 meter; Xylem, Rye Brook, NY). After being stored at -20°C, rumen fluid samples were thawed at 4°C. Following centrifugation for 20 min. at 10,000 RPM, the supernatant was used for further analysis. Flow-injection analysis was performed with a Lachat Quik-Chem 8000 FIA (Lachat Instruments). Ammonia was determined using a phenol-hypochlorite method (Method 18-107-06-1-A; Lachat) and total AA was standardized to leucine (Method 18-218-00-X; Lachat). Rumen volatile fatty acid (**VFA**) concentrations were determined by gas chromatography with a (GC-2010 Plus, Shimadzu Scientific Instruments, Columbia, MD). Results for valerate were omitted due to unreliability of the standard.

Total collection of feces and urine

The total output of feces and urine were collected for the subset of cannulated cows (n = 8) during the intensive sampling period (d 25-28). Feces and urine were weighed and sampled three times daily at 0400, 1200, and 2000 h. Each cow's feces was collected into a custom-made galvanized steel pan set beneath a grate in a gutter behind her stall. During total manure collections, wooden dividers (1.2 x 2.4 m) were bolted to partitions to span the full length of the stall to separate each cow's fecal material, with a small window in each panel allowing the cow to interact with cows in adjacent stalls. No wood shavings were used for the subset of cows undergoing total manure collection. Instead, feces were scraped into the gutter pan regularly throughout the day. At each sampling timepoint, a cow's feces were shoveled into a plastic bin and weighed on a floor scale. After mixing with a shovel, a subsample (100-150 g) was collected into a specimen cup. Feces samples were weighed immediately and dried at 55°C for 96 h for sample preservation. Urine was collected by catheterization from d 24-28 each experimental period and recorded from d 25-28 (26 Fr., 75 mL Foley balloon lubricious catheter, C.R. Bard Inc., Covington, GA). For each 8-hr interval, we acidified polyethylene urine carboys with 300 mL sulfuric acid (United States Plastic Corp., item #13891). At each sampling timepoint, we poured urine into a bucket to weigh on a floor scale, stirred it thoroughly, and sampled 100-150 mL into a specimen cup. Each urine sample was pH tested using a portable pH meter (WTW 3110 meter; WTW, Xylem, Rye Brook, NY; M = 2.8, SD = 1.3). Urine subsamples (2.0 mL) were diluted with deionized water (8.0 mL), mixed, and stored in conical tubes at -20°C. In the event of catheter expulsion, all feces and urine measurements for that cow and timepoint were discarded.

Prior to analysis, dried feces samples were composited on a DM basis within cow and period (n = 30 due to 2 missing cow-periods). To minimize analytical variation in components of N balance, total N in feeds, feces, and urine was determined with the same Dumas combustion method and equipment (Leco FP-2000 N Analyzer; Leco Corp., St. Joseph, MO; AOAC method 990.03; AOAC International, 2006). Urine samples were thawed for 24 h at 4°C and analyzed for urea and creatinine with a flow-injection analyzer (Lachat Quik-Chem 8000 FIA; Lachat Instruments) using colorimetric and picric acid methods, respectively (Zanton and Hall, 2022). To determine apparent digestibility, feces samples were analyzed using the same methods as feeds described above.

Urine output per timepoint was calculated by correcting recorded urine weights for the weight of sulfuric acid. The amounts of UN, UUN, and creatinine were first determined per timepoint by multiplying the sample concentration by the urine volume, then these values were aggregated to the day- and period-level means. Similarly, feces output per timepoint was converted to a dry matter basis by multiplying the recorded feces output (kg as-is) by the proportion of DM in its respective sample. Manure output was calculated by summing urine and feces output (kg as-is). The urea clearance rate (UCR; L/min.) was calculated as the amount of daily urinary urea-N (UUN; mg/d) divided by the mean plasma urea N (PUN; mg/dL) and converted to L/min. Apparent digestibilities were calculated by the difference between nutrient ingestion and excretion. Potentially-digestible aNDFom (pdNDFom) was calculated by the difference between aNDFom and iNDFom.

Plasma

For the cannulated subset, we collected blood from the coccygeal vessels twice daily at 0700 and 1900 h from d 25-28. Samples of approximately 8-10 mL were collected into evacuated glass tubes containing 12.15 mg of K_3 EDTA (BD Vacutainer™; Franklin Lakes, NJ), inverted several times, and placed in ice. After centrifuging samples at 1200 x *g* for 10 minutes at 4°C, we pipetted the plasma supernatant into three aliquots in 2 mL polypropylene microcentrifuge tubes and stored at -20°C. Prior to analyzing plasma samples, we diluted each plasma sample 1:1 by volume with trichloracetic acid (5% w/v), vortexed, and centrifuged for 10 minutes at 12,100 x *g* (MiniSpin; Eppendorf, Hamburg, Germany) to precipitate protein. Plasma urea-N in the supernatant was assayed with the QuantiChrom™ Urea Assay Kit (BioAssay Systems, Hayward, CA) and quantitated on an Eon™ Microplate Spectrophotometer (BioTek, Winooski, VT).

Gas emissions

We sampled gas production from the subset of non-cannulated cows using a GreenFeed (C-Lock, Rapid City, SD) headbox. The bait feed pellets included corn (90% of DM) and molasses (10% of DM). Through most of the experiment, the bait feed was included in the total mixed ration at 2% of dry matter. Cows were trained prior to starting the experiment and re-trained during d 7-14 of each experimental period. During training periods, the GreenFeed headbox was span-calibrated with pure gases. During day 14-21 of each period, we selected 4-d to sample gas production 3x/day to cover the intervals (-2.5)-(-0.5), 1-3, 4-6, 6.5-8.5, and 11-13 h relative to the 1x daily morning feeding with 12 samplings per cow per period. These timepoints were selected to over-sample (2x) the interval immediately prior to feeding so aggregate results would approximate daily methane production across expected diurnal and feeding-related variation (Sun et al., 2019). At each sampling timepoint, we removed TMR in front of a cow's stall, dispensed approximately 100 g bait feed with the GreenFeed and measured gas emissions for 5-8 minutes. For training and sampling days, the bait feed was withheld from the TMR, split into three feedings of 300 g, and fed in the GreenFeed unit (non-cannulated subset) or as a topdress (cannulated subset). Due to broken equipment, we were unable to sample gas emissions in the second experimental period. We extended the experiment 28-d to collect missing observations and changed cows back to diets used for the second experimental period. The ratio of methane (CH_4) to carbon dioxide (CO_2) was calculated on a liter per liter basis as in Madsen et al. (2010). The respiratory quotient was calculated as the quotient of the volumes (L) of CO_2 emitted and O_2 consumed, assuming densities of each gas at standard temperature and pressure.

3.3.4 Statistical Analysis

Missing data imputation

Two cows were removed from the study after contracting toxic mastitis, resulting in missing data for two cells in the Latin Rectangle design for the cannulated subset representing treatments OF-HP and SF-HP. An additional cannulated cow was substituted into the design for Period 3-4 after a toxic mastitis case in Period 2. We considered these two cells missing completely at random and modeled only the cells with available data. In addition to major missing data (two cells with no available data), technical issues such as catheter expulsion resulted in minor missing data in the cells with available data. We documented a small percentage of missing observations for milk weights and milk samples (0-2%), rumen fluid (2.6%), urine masses (5.8%), fecal masses (5.3%), urine samples (7.5%), and fecal samples (1.1%). To prevent biasing due to imbalance across time, for minor missing data we single imputed missing values using stochastic regression. The imputation model contained fixed effects and interactions for known experimental design factors including period (1, 2, 3, 4), sampling timepoint (0400, 1200, 2000), and cow (i = 1 to 9). To counteract variance attenuation, each predicted value was augmented with a random draw from the observed residual distribution (Little and Rubin, 2002).

Modeling approach

To analyze overall differences due to treatment, we modeled the mean of observed values for a given cow and period using a linear mixed model with fixed effects for experimental period (E_j, where *j* = 1, 2, 3, 4), dietary CP level (P_k, where *k* = LP, HP), CP feeding pattern (F_l, where *l* = OF, SF), and the interaction term between CP level and CP feeding pattern (PF_{kl}). We included a random effect of cow (C_i, where i = 1 to 8) and a residual error term representing the n = 30 observations (ϵ_{ijkl}).

$$y_{ijkl} = \mu + E_j + P_k + F_l + PF_{kl} + C_i + \epsilon_{ijkl}$$

For the cannulated subset, we modeled faster-responding variables over time (urine urea-N, plasma urea-N) to test for differential CP feeding pattern effects across sampling day. In these models, we added fixed effects and all possible interactions for day (*m* = 25, 26, 27, 28) and/or hour of sampling (*n* = 0400, 1200, or 2000 h for urine; *n* = 0700 or 1900 h for plasma) with treatments, and allowed the intercept to vary based on cow, period within cow, and day within period within cow, creating a block diagonal variance-covariance matrix. Given the two missing cells, the error term (ϵ_{ijklmn}) describes n = 360 urine or n = 240 plasma observations.

$$y_{ijklmn} = \mu + E_j + P_k + F_l + PF_{kl} + D_m + H_n + (D_m \times H_n)$$
$$+ D_m(P_k + F_l + PF_{kl})$$
$$+ H_n(P_k + F_l + PF_{kl})$$
$$+ (D_m \times H_n)(P_k + F_l + PF_{kl})$$
$$+ C_i + (C{:}E)_{ij} + (C{:}E{:}D)_{ijm} + \epsilon_{ijklmn}$$

We conducted all data analysis using R version 4.1.2 (R Core Team, 2021). We considered $P < 0.05$ significant and $0.05 \leq P \leq 0.10$ tendencies. When standard errors differed due to imbalance between cells, we reported the greatest standard error. Analysis was conducted separately for the cannulated and non-cannulated subsets. We fit models using the lme4 and lmerTest packages (Bates et al., 2015; Kuznetsova et al., 2017) using restricted maximum likelihood. We computed Type III sums of squares using afex (Singmann et al., 2022) and least squares means using the emmeans package (Lenth, 2016). To test for temporal patterns in dynamic N variables, we examined the interactions of CP level and CP feeding pattern with sampling day. Sampling day was considered a categorical variable to allow for non-linear responses.

3.4 Results and Discussion

Our study examined rumen fluid characteristics, nutrient digestibility, N balance, N efficiency, and GHG emissions associated with two levels of dietary CP (LP, HP) and two CP feeding patterns (OF, SF). Predictions from the NASEM (2021) model presented in a companion paper (Erickson et al., 2023) indicated that energy was oversupplied in all experimental diets, and MP supply was centered at 94% (LP) and 104% (HP) of requirements. In the oscillating feeding pattern, varying dietary CP concentration ± 1.8% of DM resulted in diets where MP supply differed by 465 to 472 g/d between lower- and higher-CP phases (MP supply in OF-LP =

83 to 104% and OF-HP = 94 to 114% of MP requirement). Because we tested the effect of CP feeding pattern at multiple levels of CP, our research contributed to understanding potential interactions between CP level and FP. We hypothesized that CP feeding pattern would maintain production, enhance digestibility, and reduce environmental outputs of mid- to late-lactation cows for LP but not HP. The milk production response is detailed in a separate manuscript (Erickson et al., 2023). However, selected milk and production variables are included for subsets of cows when relevant to the interpretation of results.

3.4.1 Rumen Environment

Compared to LP, ruminal ammonia-N concentrations were 26% greater with HP, yet average TAA concentrations were similar (Table 1). CP level affected the pattern of ammonia-N and tended to affect total AA over time relative to feeding (Supplemental Figures). In a review of research, Schwab and Broderick (2017) suggested that ruminal ammonia levels of 5 to 11 mM (7.0 to 15.4 mg/dL) may be optimal to maximize microbial N outflow and OM digestibility. Still, these authors noted that optima were diet-specific. Limited research has considered lower-CP diets. Studies have shown that lower dietary CP, monensin supplementation, and greater dietary starch can independently reduce ruminal ammonia-N concentrations (Recktenwald et al., 2014; Belanche et al., 2012), all of which may have contributed to the low ammonia-N concentrations observed in our trial. Interestingly, we found no effects of feeding pattern on ruminal ammonia-N or TAA concentrations, which contrasted Kohler's (2016) finding of greater ammonia-N with oscillating dietary CP. Future work is needed to determine how ruminal conditions relate to ruminal OM digestibility and microbial N outflow on lower-CP, higher-starch diets such as diets designed to reduce reactive N losses.

Ruminal concentrations of the major VFA acetate, propionate, and butyrate were unaffected by dietary protein level in our trial. With static CP feeding patterns, other authors (e.g., Aguerre et al., 2016; Olmos Colmenero and Broderick, 2006) observed no effect or modest responses in concentrations of major VFA due to changes in dietary CP. In contrast to other work (e.g., Kidane et al., 2018) which found greater iso-butyrate and a tendency for greater iso-valerate with higher dietary CP, we found no effects of dietary CP level on BCVFA concentrations in our trial. Recent studies that oscillated dietary CP *in vitro* and *in vivo* also showed minimal effects of feeding pattern on VFA concentrations. We found that concentrations of iso-valerate tended to be 11% greater in SF compared to OF, which could indicate small differences in microbial community structure or function, given that DMI and other diet factors were similar across these conditions. Ruminal concentrations of most analytes varied across sampling timepoints and days, with few treatment by time interactions (Supplemental Figure 1, Appendix). Whereas ruminal ammonia-N and TAA concentrations appeared to spike after feeding, the total concentration of major VFA rose more gradually throughout the day. Tendencies for FP*Day interactions suggested differences in ammonia-N and total AA across higher-CP and lower-CP feeding phases (Supplemental Fig. 1). Taken together, our results suggested minimal effects the dietary CP difference (13.8 vs. 15.5% of DM) and the feeding pattern (OF vs. SF) on ruminal fermentation patterns.

3.4.2 Nutrient Digestibility and Manure Output

Apparent nutrient digestibility and manure output results are shown in Table 2. We observed no effect of CP level, CP feeding pattern or their interaction in most cases, except that urine output and consequently manure output were greater with HP than LP. Intake of DM, OM, aNDFom, and pdNDFom were similar across LP and HP conditions in our trial, which indicated that our diets successfully increased N intake while minimally disturbing DMI and the dietary carbohydrate fraction. Apparent total-tract nutrient digestibilities were also similar for LP and HP. Considering that dietary changes in NDF, starch, and CP in our trial were moderate, we did not expect differences in digestibility due to CP level. Previous research showed that altering dietary carbohydrate and protein fractions had modest impacts on nutrient digestibilities when dietary carbohydrate and N were close to requirements. A meta-analysis by de Souza et al. (2018) found only a slight (0.59%) depression in NDF digestibility associated with 1% greater starch content holding other factors constant. Previously, Aguerre et al. (2016) reported that increasing CP from 15.3 to 16.6% of diet DM increased DM, OM, and CP digestibility and had no effect on NDF digestibility. Using more extreme N-deficient diets than our trial, Belanche et al. (2012) reported that increasing dietary CP from 11 to 14% (80 vs. 110% of digestible N requirement) increased OM digestibility with concurrent shifts in the rumen microbial composition. Importantly, greater dietary CP generally increases apparent CP digestibility due to the dilution of metabolic fecal protein (NRC, 2001). Although CP digestibility was numerically greater for HP than LP in our trial, CP level had few effects on nutrient digestibility overall.

Neither nutrient intakes nor apparent total tract digestibilities differed due to CP feeding pattern or the interaction of CP level and CP feeding pattern, which was contrary to prior research. Several recent authors observed that oscillating CP feeding patterns increased digestibility of CP (Tebbe and Weiss, 2020; tendency) and DM, OM, CP, NDF, and starch (Rauch et al., 2021), yet failed to improve milk and component production. These authors suggested that oscillating CP feeding pattern may have decreased post-absorptive nutrient efficiency through unclear mechanisms. Importantly, DMI and N intake were either reduced (Tebbe and Weiss, 2020) or similar (Rauch et al., 2021) for oscillating vs. static CP feeding pattern. Interestingly, Kohler (2016) found that oscillating CP feeding pattern increased DM ruminal digestibility and tended to increase OM ruminal digestibility relative to static but had no effects on total tract apparent digestibility of DM, OM, CP, NDF, or ether extract. In our trial, the lack of CP feeding pattern or CP-level by feeding pattern interaction on nutrient intake and digestibility does not rule out mechanistic differences in digestion. Still, our results indicated no compensatory gains in CP or OM digestibility resulting from the 48-hr oscillating diets.

The range of manure output in our trial was similar to that observed on similar diets in past research (Wattiaux and Karg, 2004; Nennich et al., 2006) and predicted output based on DMI (NASEM, 2021). Output of manure tended to increase with HP, driven by an increase in urine output with HP. Conversely, CP level had no effect on output of feces or fecal DM. Crude protein feeding pattern did not affect output of manure, urine, feces, or fecal DM and no CP-level by CP feeding pattern interactions were apparent. Our results are similar to those of Tebbe and Weiss (2020), who observed increased urine and manure output with greater dietary CP but no effect of oscillating CP feeding pattern. Likewise, Kohler (2016) reported no differences in fecal DM or urine due to CP feeding pattern. Our results support the contention that 48-hr oscillating diets in our trial did not alter urine or manure output on average, although greater and lesser dietary CP likely induced transient changes in manure output via urine volume.

Over the 4-d experimental period, a interaction of day-by-feeding pattern showed that OF and SF urine output followed different temporal patterns (Figure 1). For OF, urine output increased during most of the higher-CP phase and rapidly decreased after the initial lower-CP phase feeding. In contrast, urine output for SF appeared more stable. In our trial, diet changes were made by exchanging dry concentrates and DMI was stable across time (Erickson et al., 2023). Thus, intake of dietary water was stable. However, we did not measure *ad libitum* water intake. Several reports showed that increased dietary CP tended to increase voluntary water intake, which may increase urine output (Holter and Urban, 1992; Tebbe and Weiss, 2020). It is notable that urine output responded to short-term changes in dietary CP even after adaptation to the OF condition, which suggests that voluntary water intake quickly responded to changes in dietary CP.

3.4.3 N Balance

Results for N balance for the cannulated subset are shown in Table 3. We found CP influenced certain N variables, but there were no effects of feeding pattern or the interaction. In general, the amounts and percentages of N in excreta were consistent with prior research (Olmos Colmenero and Broderick, 2006; Lee et al., 2019). As designed, N intake was greater with HP and unaffected by CP feeding pattern. Milk N output was unaffected by CP level, but HP increased urine N output and tended to increase fecal N output. This suggests the additional CP consumed and digested in HP exceeded capacity for milk protein synthesis and instead was directed primarily to manure N excretion. Assuming no other nutrient deficiencies limited the milk protein response, this means that CP level in our study was more optimal at LP than HP because LP resulted in similar production with lesser manure N excretion. This is consistent with recent research showing a lack of milk protein response to additional dietary CP in late lactation (Mutsvangwa et al., 2016; Barros et al., 2017; Letelier et al., 2022). However, the similar milk protein response between LP and HP did not reflect the NRC (2001) model we used in ration formulation, which predicted that LP would constrain production. Updates published in the NASEM (2021) model revealed that NRC (2001) in general overestimated MP requirements. It is well-established that decreasing dietary CP can not only improve the efficiencies of MP and AA use by tissues (Lapierre et al., 2007; NASEM, 2021), but also enhance recapture of N via urea-N recycling (Reynolds and Kristensen, 2008). Indeed, our trial found UCR was lower with LP, suggesting lower glomerular filtration or higher reabsorption of urea-N by the kidneys

(Müller et al., 2021; Souza et al., 2021).This is consistent with literature reviewed and meta-analyzed by Spek et al. (2013b) where renal reabsorption of urea appeared to increase (or glomerular filtration rate decreased) as dietary CP decreased from approximately 17 to 13%. Under the conditions in our trial, our results showed that N balance was similar for late-lactation, multiparous cows with CP at 13.8% (vs. 15.5%) except that a lesser fraction of intake N was excreted in manure.

Although we noted no differences in apparent N retention amount or percentage between LP and HP, our trial was not designed to measure changes in BW or body composition. Indeed, in our trial, the greater creatinine excretion with HP could indicate that cows fed HP not only excreted more N, but also gained protein reserves in skeletal muscle during the adaptation period (Valadares et al., 1999). Liu et al. (2021) recently showed that individual cows' milk production responses to dietary CP were uncorrelated with their responses in empty BW gain. This could indicate that cows in our trial gained additional BW, partitioning N to BW instead of milk N. In contrast to our N balance measurements over four days, Liu et al. (2021) used repeated BW measurements to show lower-CP (13% vs. 16%) decreased gains of body reserves in late lactation. Using the urea dilution method, Tebbe and Weiss (2020) showed minimal changes in BW composition in late lactation cows fed two dietary CP levels (14.1 and 16.2%). Future studies examining the implications of lower dietary CP on BW and BCS in late lactation are warranted.

Contrary to our hypothesis, we found no evidence for differential effects of CP feeding pattern at different dietary CP levels. CP feeding pattern had no effect on the amount of N or percentage of intake N allocated to measured body and excreta pools. Our results agree with several recent studies showing no difference in NUE for oscillating and static CP (Kohler, 2016; Tebbe and Weiss, 2020; Rauch et al., 2021a). However, our findings contrast reports of minor differences in the partitioning of N in excreta. For example, when feeding an average 17.1% CP (oscillating ± 3.0 %), Kohler (2016) reported greater residual N that suggested increased N retention with oscillating CP compared to static. In contrast, Tebbe and Weiss (2020) found a greater fraction of intake N was allocated to urine and a lesser fraction to retention with oscillating CP. In Tebbe and Weiss's (2020) trial, average dietary CP (14.1%) was comparable to our LP condition, yet the oscillating CP condition reduced N intake, which may have had downstream effects. Taken together, our results and the literature suggest that oscillating CP had limited effects on whole-body N usage at any of the average CP levels tested. The lack of effect on gross N outputs suggests that mid- to late-lactation cows in our trial tolerated ±1.8% variation in dietary CP level at 48-hr intervals, with dietary CP as low as 12.2% for the lower-CP phase of OF-LP. This demonstrates that late lactation cows have a degree of flexibility in N metabolism that could be leveraged in diet formulation and feeding practices. For example, it may be possible to control CP composition of diets within larger safety margins rather than investing technological, financial, and human resources in excessive precision.

In our trial, the difference in urinary N output for LP and HP was primarily accounted for by additional urinary urea N yield (**UUNY**; 93.5%), comparable to values of 96-100% reported in prior work which examined differences between CP levels greater than those in our trial (Wattiaux and Karg, 2004). In our trial both UUN and UUNY were greater with HP than LP. This was similar to previous research (e.g., Burgos et al., 2007) but contradicted the results of Wattiaux and Karg (2004) where increasing dietary CP had no effect on UUN but increased UUNY via an increase in urine volume. As discussed previously, consistent with our study (Table 3), previous work associated greater protein intake with greater urine volume due to increased voluntary water consumption (Van Vuuren and Smits, 1997; Sannes et al., 2002; Broderick, 2003). As a predictor of urine volume, water intake is an important determinant of

UUN (Dijkstra et al., 2013a). UUN was lower for OF than SF, although UUNY did not differ due to CP feeding pattern. Urine volume was numerically, but not statistically, greater with OF than SF. Given that UUNY, PUN, and UCR did not differ due to CP feeding pattern, UUN may reflect differences in voluntary water intake that resulted in more dilute urine with OF when averaged over time. Tebbe and Weiss (2020) showed that free water intake tended to be greater with greater dietary CP, and free and feed water intake did not differ due to CP feeding pattern. Our trial allowed *ad libitum* access to water and we did not measure water intake. Future work could investigate whether CP feeding pattern alters voluntary water intake patterns, explaining the dilution of UUN with OF compared to SF. Bannink et al. (1999) reported that N intake did not explain a significant amount of variance in urine volume above that explained by dietary intake of Na and K. In our study, the total absorbable supply predicted by NRC (2001) for Na and K differed minimally between LP and HP (<1 and <15 g, respectively), and the range of Na and K between lower and higher-CP phases of OF was small (<10 and <30 g, respectively). Based on the coefficients reported by Bannink et al. (1999), the minor increases in Na and K with greater CP in our trial were predicted to minimally affect urine volume.

3.4.4 Temporal Responses in Urine and Plasma Nitrogenous Compounds

Figure 1 shows the amount (UUNY) and concentration (UUN) of urea-N in urine and the urea-N concentration in plasma (PUN) over time. UUNY, UUN, and PUN were consistently greater for HP than LP. Although CP feeding pattern did not affect UUN or PUN when averaged across timepoints as discussed in the previous section, Figure 1 shows significant day by CP feeding pattern interactions where urea-N in plasma and excreta rose and fell in response to changes in dietary CP. The non-significant three-way interaction indicated the day by CP feeding pattern effect was similar regardless of CP level. For SF, UUNY, UUN and PUN appear relatively consistent across time. In contrast, for OF, UUNY, UUN, and PUN gradually rose after the start of higher-CP feeding and fell after lower-CP feeding. These patterns are similar to a rise and fall in milk urea-N concentration and yield reported in our earlier paper describing all 16 cows (Erickson et al., 2023). Most existing research has studied the effects of dietary N on UUN, UUNY, and PUN after adaptation to a time-invariant dietary CP level (e.g., Barros et al., 2019). In contrast, our research examined these relationships after adaptation to a condition with time-varying dietary CP (OF) compared with time-invariant dietary CP (SF). Because these temporal patterns represent the response to dietary CP within cow and period, the rise and fall in OF relative to SF likely isolates differences due to diet, independent of cow and contextual factors (e.g., changes in BW, season, or stage of lactation). Therefore, it is interesting to note that the ranges in UUNY of 38.7 g/8-hr for OF-HP and 37.9 g/8-hr for OF-LP align with previous meta-analyses of treatment means. Spek et al. (2013a) and Powell et al. (2011) suggested a 1% increase in dietary CP was associated with an increase of 28-32 g UUNY/d, or 9.3 to 10.7 g UUNY/8-hr. This implies that the 3.5% difference in dietary CP from the lower- to higher-CP phases for OF conditions would result in a 35 g/8-hr difference in UUNY. Our results demonstrate that the dietary CP to UUNY relationships established with meta-analyses (e.g., Powell et al., 2011; Spek et al., 2013a) are true not only after long-term (1-3 wk.) adaptation to a given dietary CP level, but also when CP changes at shorter intervals such as the 48-hr interval in our trial.

3.4.5 Nitrogen and Feed Efficiency Metrics

Feed efficiency and NUE were similar across conditions in our trial, except that greater dietary CP worsened NUE (32.1 vs. 28.7%; Table 4, n = 16 cows). More specifically, HP increased N intake yet did not improve milk production which suggests that the additional dietary CP was excreted as manure N or retained in body tissues (Dijkstra et al., 2013; Powell et al., 2011). This is consistent with prior research demonstrating NUE generally decreases with increasing N intake (Reynal and Broderick, 2005; Brito and Broderick, 2006; Spanghero and Kowalski, 2021). Although NUE can be affected by dietary protein digestibility (Broderick et al., 2009), digestion kinetics (Mutsvangwa et al., 2016), and AA composition (Gidlund et al., 2015), our diets were designed to minimize differences in RDP:RUP ratios and AA profiles across treatments. Still, considering that reducing NDF and increasing starch may improve NUE independent of dietary CP (Broderick, 2003) it is plausible that part of the observed improvement in NUE in our trial was attributable to the greater inclusion of fermentable carbohydrate in LP rations. Similar to our findings, CP feeding pattern did not affect NUE in recent trials (Kohler, 2016; Tebbe and Weiss, 2020b; Rauch et al., 2021), although these trials suggested possible differences in aspects of N metabolism. In our trial, feed efficiencies did not differ across experimental conditions because DMI and milk production were similar across CP levels and CP feeding patterns. Our findings corroborate research showing that increasing CP above requirements did not improve milk production performance (Barros et al., 2017; Broderick et al., 2009), and that various oscillating CP feeding patterns did not alter feed efficiency (Tebbe & Weiss, 2020; Kohler, 2016; Rauch et al., 2021).

Compared with HP-feeding, LP feeding had greater MPY/MUNY (248 versus 328 g/g, respectively, $P < 0.001$; Table 4). Interestingly, although CP feeding pattern did not affect NUE in our trial, OF tended to increase the MPY/MUNY ratio relative to SF (295 vs. 281 g/g, $P = 0.066$; Table 4). Authors suggested MPY/MUNY ratio as a practical indicator of N efficiency (Barros et al., 2017; Chen et al., 2022) because its components are easily measurable and differentiate milk N secretions with economic value (milk true protein) from non-protein N that is irreversibly lost from the animal. With late-lactation cows, Barros et al. (2017) suggested that

MPY/MUNY ratio less than 276 reflected excess dietary CP or poor utilization of dietary CP whereas MPY/MUNY greater than this threshold could indicate dietary CP deficiency. However, under the conditions of our study, it appears that MPY/MUNY ratio as high as 328 (average for LP diets) was not associated with adverse milk production or milk composition outcomes (Table 4). The differences in MPY/MUNY require further investigation as they suggest that N metabolism differed based on CP level and potentially CP feeding pattern. Contrary to our hypothesis, there is no evidence for an interaction.

3.4.6 Gas Emissions

Table 5 shows gas production, intensity, and yield for the non-cannulated subset in our trial. Results suggested minimal differences in gas emissions related to CP level and CP feeding pattern. Emissions of CH_4 and CO_2 in our trial were comparable to recent reports with similar dietary and cow conditions (Lage et al., 2021). Our results are consistent with Müller et al. (2021) which reported no differences in production of CH_4 and CO_2 and oxygen consumption when lowering protein and increasing starch (13.8% CP) relative to a higher-CP diet (15.9% CP), and Niu et al. (2016) which found no differences in enteric CH_4 production, intensity, or yield when comparing 15.2 and 18.5% dietary CP in a crossover study. In contrast, Gidlund et al. (2015) reported reduced CH_4 yield at moderate dietary CP (18.4-19.1%) compared to higher and lower dietary CP extremes (17.0-17.3% and 20.1-21.0%) where dietary NDF and pdNDF were similar across conditions. Importantly, NDF and pdNDF changed modestly between LP and HP diets in our trial. The absence of CP level and CP feeding pattern effects suggests that conditions for methanogenesis (e.g., substrate availability, microbial community structure and fermentation activity) were similar among conditions.

Interestingly, we found that HP diets, especially OF-HP, tended to promote greater CO_2 production. In ruminants, enteric CH_4 production is largely determined by rumen fermentation capacity and fermentation patterns, whereas CO_2 arises predominantly from respiration and to a lesser extent from fermentation (Madsen et al., 2010). It is unclear whether CO_2 differences were caused at the rumen-level, e.g., by alterations to microbial biomass, species composition, or substrate usage, or at the whole-animal level, e.g., via changes in macronutrient metabolism, body composition, and maintenance requirements. Talal et al. (2020) suggested that greater CO_2 yield could occur with lipogenesis or upregulation of the pentose phosphate pathway. Tissue protein turnover could consume oxygen and produce CO_2 without affecting CH_4 production (Hanigan et al., 2009). Additionally, CO_2 emissions could be affected by bicarbonate usage in body buffering systems which HP diets may have affected by increasing urea transport into the rumen and into urine (Laporte-Uribe, 2019; Tebbe and Weiss, 2020). Tracking fermentative and respiratory emissions may increase in importance with carbon measurement and accounting schemes.

3.5 Conclusions

Our trial tested the effects of CP level, CP feeding pattern, and the interaction on N balance, nutrient digestibility, and gas emissions with mid- to late-lactation Holstein cows. Contrary to our hypothesis, CP feeding pattern had minimal effects on measured variables, regardless of the average CP level (LP = 13.8 vs. HP = 15.5% of DM). CP level did not alter milk N. Instead, HP led to effects consistent with N overfeeding, such as increased UUNY, UUN, and UCR, and reduced NUE. Time series analysis of UUNY, UUN, and PUN showed that these body and excreta urea-N pools responded to increased and decreased dietary CP within 48-hr intervals (2 feedings) and that responses to dietary N were consistent with previous meta-analytical research. Interestingly, HP increased urinary creatinine excretion and CO_2 production was greater for OF-HP, which could suggest differences in body composition and macronutrient metabolism. In summary, the 48-hr dietary CP oscillations in our trial had minimal effects on N balance, nutrient digestibility, and gas fluxes at CP levels near (HP) or below (LP) predicted requirements.

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3.8 Tables and Figures

Table 3.1. Rumen fluid analyte least squares means, standard errors, and *P*-values for *F*-tests of treatment effects across d 25-28 of each period (n = 8 cows).

CP Level	LP		HP			*P*-values		
CP Feeding Pattern	OF	SF	OF	SF	SEM	CP level	CP feeding pattern	Interaction
pH	6.35	6.38	6.37	6.38	0.04	0.72	0.41	0.62
N components								
NH_3–N (mg/dL)	1.76	1.92	2.30	2.35	0.14	<0.001	0.29	0.57
Total AA (mM)	2.70	2.82	2.56	2.50	0.2	0.25	0.88	0.65
VFA concentration (mM)								
Acetate	55.8	54.7	55.6	54.8	1.1	0.99	0.38	0.92
Propionate	19.0	18.6	19.5	19.8	0.7	0.21	0.93	0.55
Butyrate	11.7	11.9	11.8	11.8	0.5	0.88	0.79	0.74
Major VFA	86.4	85.2	86.9	86.4	1.7	0.63	0.63	0.82
Iso-valerate	1.27	1.38	1.35	1.52	0.08	0.14	0.07	0.64
Iso-butyrate	0.54	0.53	0.57	0.60	0.04	0.21	0.79	0.50
Total iso-acid	1.81	1.91	1.91	2.12	0.10	0.14	0.14	0.57

Table 3.2. Apparent nutrient digestibility and manure output, least squares means, standard errors, and contrasts. n = 8 cows in cannulated subset.

CP Level	LP		HP			*P*-values		
CP Feeding Pattern	OF	SF	OF	SF	SEM	CP level	CP feeding pattern	Interaction
Intake[1]								
DM, kg	25.1	24.3	25.4	25.2	1.1	0.417	0.504	0.707
OM, kg	24.1	23.3	24.2	24.1	1.0	0.475	0.523	0.615
aNDF, kg	7.2	7.0	6.9	6.7	0.3	0.159	0.256	0.932
aNDFom, kg	7.0	6.8	6.8	6.6	0.3	0.117	0.248	0.909
pdNDFom, kg	5.2	5.0	4.9	4.8	0.2	0.100	0.319	0.605
Apparent digestibility, %								
DM	70.0	68.9	69.8	69.6	1.3	0.838	0.577	0.707
OM	73.2	72.3	73.2	73.1	1.2	0.693	0.607	0.689
aNDF	48.0	45.5	46.4	45.4	2.8	0.731	0.474	0.739
aNDFom	50.5	48.2	48.7	48.6	2.5	0.736	0.562	0.592
pdNDFom	64.6	63.4	65.6	66.4	2.1	0.230	0.896	0.550
CP	69.3	68.9	70.8	70.8	1.3	0.173	0.836	0.863
Output[2]								
Manure, as-is, kg	78.2	75.5	83.8	80.7	4.4	0.081	0.340	0.954
Urine, as-is, kg	25.5	23.4	29.5	28.9	2.2	<0.001	0.197	0.452
Feces, as-is, kg	52.7	52.1	54.2	51.7	3.0	0.789	0.474	0.664
Fecal DM, kg	7.5	7.6	7.7	7.5	0.4	0.744	0.882	0.686

1. Based on quantity of feed offered and refused during the last 4-d of each 28-d sampling period and chemical composition of feed, feces, and orts samples.
2. From 4-d total collection and sampling of feces and urine.
3. pdNDF = potentially digestible NDF
4. aNDFom = NDF treated with α-amylase and Na_2SO_3 and corrected for ash content

Table 3.3. Nitrogen balance from total collection and milk sampling across 4-d. Least squares means, standard errors, and contrasts for n = 8 cows in the cannulated subset. [1] Cows were fed combinations of crude protein (CP) low protein (LP) or high protein (HP), and oscillating (OF) or static (SF).

CP Level	LP		HP			*P*-values		
CP Feeding Pattern	OF	SF	OF	SF	SEM	CP Level	CP Feeding Pattern	Interaction
Milk, kg/d	39.8	37.9	39.3	38.9	2.0	0.806	0.190	0.371
FPCM, kg/d	37.0	36.6	37.2	37.6	1.5	0.444	0.987	0.656
BW	665.8	664.2	673.1	676.2	23.6	0.250	0.929	0.780
BCS	3.14	3.14	3.24	3.16	0.09	0.171	0.438	0.399
Nitrogen, g/d								
Intake	555	534	632	624	26	<0.001	0.425	0.700
Milk	178	172	181	178	8	0.395	0.422	0.851
Urinary	153	155	210	205	8	<0.001	0.819	0.519
Fecal	170	168	186	180	9	0.075	0.575	0.786
Residual	55	39	56	63	16	0.293	0.673	0.332
Nitrogen, % of intake N								
Milk	32.7	32.6	29.7	28.9	1.2	<0.001	0.250	0.410
Urinary	28.6	29.3	34.4	33.2	1.0	<0.001	0.777	0.200
Fecal	30.9	31.5	29.8	29.1	1.3	0.184	0.959	0.624
Manure	59.6	60.8	64.4	62.3	1.8	0.075	0.789	0.338
Residual	7.9	6.5	6.2	8.7	2.4	0.902	0.751	0.268
Urinary components								
Creatinine, mg/L	664	680	582	611	42	0.002	0.288	0.744
Creatinine, mg/d	16942	16645	17554	17422	614	0.019	0.451	0.760
UUN, g/L	3.55	4.10	4.70	4.91	0.32	<0.001	0.049	0.321
UUNY, g/d	93	98	146	142	6	<0.001	0.871	0.300
PUN, mg/dL	10.9	11.5	14.8	14.6	0.5	<0.001	0.485	0.182
UCR, L/min.	0.60	0.60	0.70	0.69	0.04	0.005	0.983	0.898

1. FPCM = fat- and protein-corrected milk; BCS = body condition score from a scale in 0.25 increments from 1 (thin) to 5 (obese); PUN = plasma urea nitrogen, UUN = Urine Urea-N concentration, UUNY = Urine Urea-N yield, UCR = Urea clearance rate.

Table 3.4. N efficiency metrics least squares means, standard errors, and contrasts for n = 16 cows. Treatments represented two levels of crude protein (low protein, LP = 13.8% of DM; high protein, HP = 15.5% of DM), and two feeding patterns with crude protein in oscillating (OF) or static (SF) patterns.

Crude Protein Level	LP		HP			*P*-values		
Feeding Pattern	OF	SF	OF	SF	SEM	CP level	CP feeding pattern	Interaction
NUE[1], g/g	31.9	32.3	29.0	28.4	0.8	<0.001	0.764	0.266
MPY/MUNY[2], g/g	333	322	256	240	9	<0.001	0.066	0.736
Milk yield/DMI, kg/kg	1.55	1.56	1.54	1.54	0.05	0.447	0.660	0.866
FPCM[3]/DMI, kg/kg	1.49	1.53	1.51	1.52	0.04	0.880	0.344	0.709

1. NUE = Nitrogen Use Efficiency
2. MPY/MUNY = ratio of milk protein yield (g) to milk urea-N yield (g)
3. FPCM = fat-protein-corrected milk.

Table 3.5. Gas emissions, oxygen consumption, and respiratory quotient. Least squares means, standard errors, and contrasts. n = 8 cows in non-cannulated subset.

CP Level	LP		HP			*P*-values		
CP Feeding Pattern	OF	SF	OF	SF	SEM	CP level	CP feeding pattern	Interaction
DMI, kg/d	26.4	26.8	26.4	25.9	1.0	0.401	0.935	0.442
Milk, kg/d	37.0	36.7	37.2	35.9	1.5	0.729	0.350	0.597
FPCM, kg/d	37.5	36.3	37.2	36.2	1.6	0.823	0.270	0.934
BW	657	660	669	662	20.8	0.463	0.854	0.590
BCS	3.14	3.14	3.19	3.16	0.11	0.486	0.787	0.706
CH_4								
Production, g/d	473	473	483	466	26	0.892	0.477	0.461
Intensity, g/kg FPCM	12.71	13.04	13.24	13.00	0.69	0.585	0.922	0.539
Yield, g/kg DMI	17.94	17.53	18.45	18.14	0.78	0.280	0.491	0.917
CO_2								
Production, g/d	14,827	14,870	15,597	14,890	410	0.070	0.123	0.084
Intensity, g/kg FPCM	402	417	427	419	19	0.231	0.734	0.329
Yield, g/kg DMI	564	557	595	586	16	0.022	0.474	0.927
CH_4/CO_2, L/L	0.964	0.950	0.931	0.943	0.004	0.309	0.950	0.497
Oxygen consumption	10,202	10,223	10,603	10,421	332	0.102	0.646	0.565
Respiratory quotient	1.05	1.05	1.07	1.03	0.02	0.865	0.268	0.263

1. Based on quantity of feed offered and refused during the last 4-d of each 28-d sampling period and chemical composition of feed, feces, and orts samples.
2. From 4-d total collection and sampling of feces and urine.
3. pdNDF = potentially digestible NDF
4. aNDFom = NDF treated with α-amylase and Na_2SO_3 and corrected for ash content

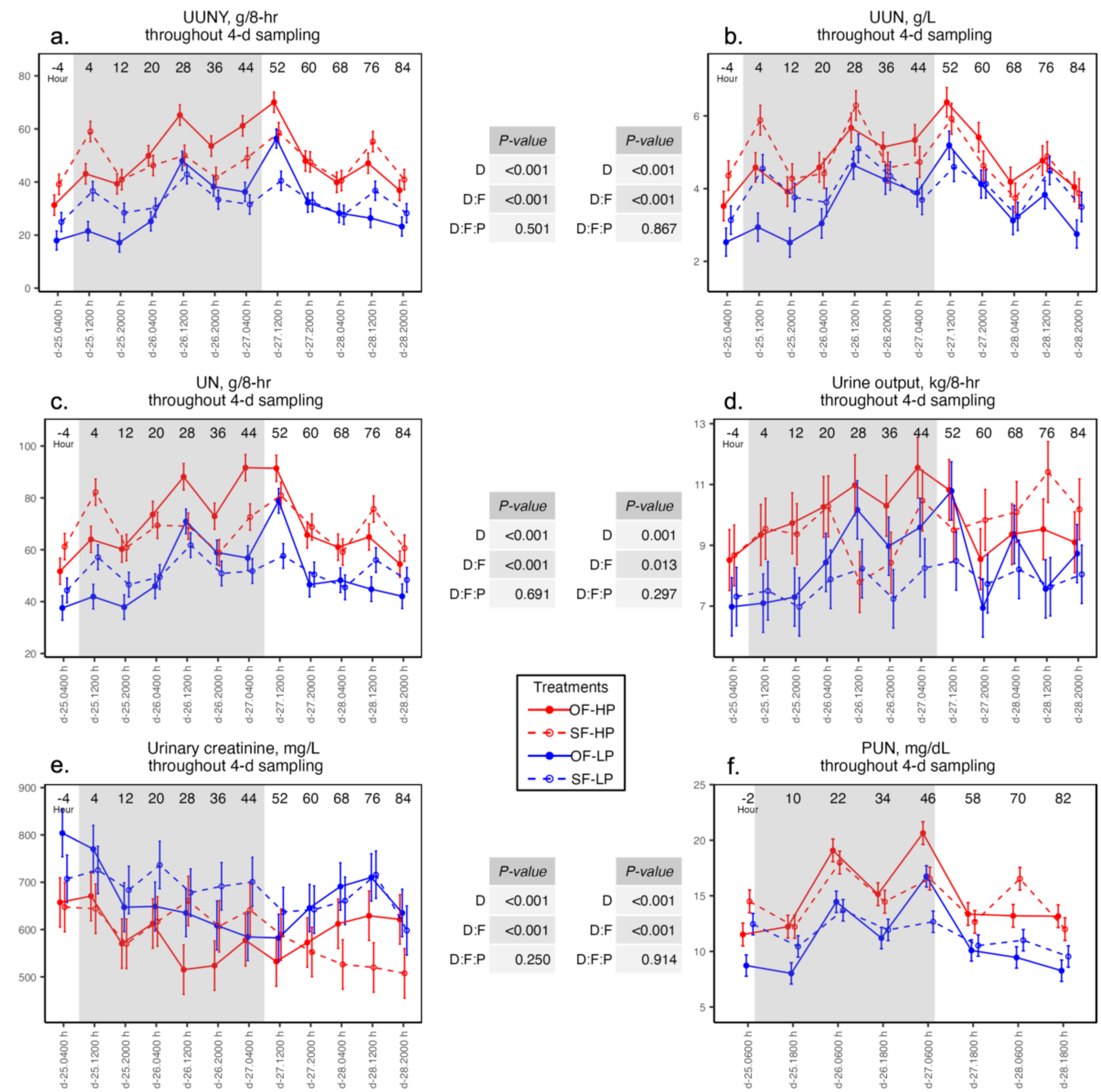


Figure 3.1. Temporal patterns in variables with significant feeding pattern by day interactions: a) Urine urea-N yield (UUNY, g/8-hr), b) urine urea-N concentration (UUN, g/L), c) urinary N (g/8-hr), d) urine output (kg/8-hr), e) urine creatinine (mg/L), and f) plasma urea-N concentration (PUN, mg/dL). Results of F-tests for day (D) by feeding pattern (F) and crude protein level (P) are shown in tables. A grey rectangle shows the higher-*CP* phase *in OF*. Points show least squares means from linear mixed models with F, P, F:P, D, and sampling hour (H), with all possible interactions between temporal and treatment variables. Plots represent n = 360 (UUNY, UUN) and n = 240 (PUN) observations from n = 8 cows in the cannulated subset, across a 4-d sampling period under conditions of oscillating high protein (OF-HP, 15.5±1.8% crude protein), and oscillating low protein (OF-LP, 13.8±1.8% crude protein).

3.9 Appendix

Supplementary Table 1. Variance components and autocorrelation parameters for analytes in ruminal fluid.[1]

	τ_{00}				
Variable	Day in Period in Cow	Period in Cow	Cow	σ^2_ε	ϕ
pH	0.091	0.012	0.075	0.055	0.1436
N components					
NH_3–N (mg/dL)	0.283	0.017	0.357	0.763	0.0416
Total AA (mM)	0.140	0.271	0.001	4.382	0.0502
VFA concentration (mM)					
Acetate	0.993	1.038	2.637	101.499	0.0472
Propionate	1.162	0.413	2.868	16.859	-0.0248
Butyrate	0.959	0.429	0.487	8.606	0.1034
Major VFA	1.148	0.406	6.082	249.035	0.0202
Iso-valerate	0.064	0.009	0.322	0.202	0.2551
Iso-butyrate	0.001	0.001	0.175	0.043	0.1155
Total iso-acid	0.006	0.007	0.476	0.394	0.2195

1. τ_{00} is the random intercept variance expressed as a standard deviation; σ^2_ε is the residual variance; ϕ is the autocorrelation parameter.

Supplementary Table 2. *P*-values for F tests of time effects and treatment by time interaction effects for urine and plasma parameters.

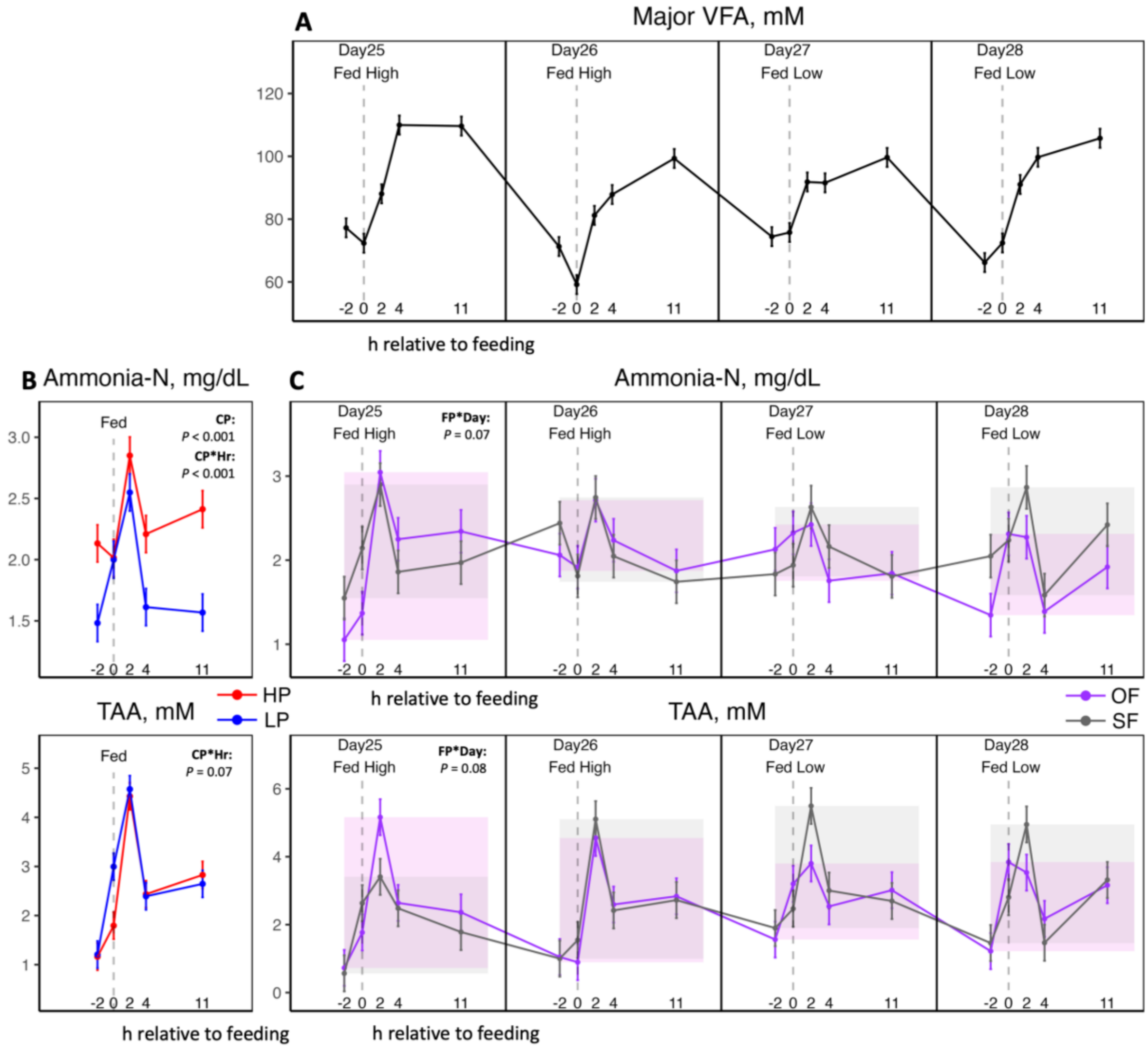
	P-value[1]												
Variable	E	D	H	F:D	P:D	F:H	P:H	D:H	F:P:D	F:P:H	F:D:H	P:D:H	F:P:D:H
Urine													
Output, kg/8-h	0.10	0.00	0.04	0.01	0.59	0.47	0.83	0.04	0.30	0.95	0.01	0.04	0.98
N, g/8-h	0.01	<0.001	<0.001	<0.001	0.27	0.72	0.24	0.03	0.69	0.62	<0.001	0.14	0.61
Creatinine, mg/L	<0.001	<0.001	<0.001	<0.001	0.36	0.87	0.94	0.06	0.25	0.76	0.26	0.64	0.48
Creatinine, mg/8-h	<0.001	0.86	<0.001	0.61	0.42	0.53	0.61	0.15	0.89	0.97	0.26	0.11	0.60
Urea-N, g/L	0.01	<0.001	<0.001	<0.001	0.25	0.11	0.24	0.28	0.87	0.23	0.47	0.80	0.89
Urea-N, g/8-h	<0.01	<0.001	<0.001	<0.001	0.63	0.95	0.34	0.02	0.50	0.81	<0.001	0.07	0.72
Plasma Urea-N, mg/dL	<0.001	<0.001	<0.001	<0.001	0.41	0.89	0.29	<0.001	0.91	0.12	<0.01	0.73	0.81

1. Effects for experimental period (E_j, where j = 1, 2, 3, 4), dietary CP level (P_k, where k = LP, HP), CP feeding pattern (F_l, where l = OF, SF), and interactions are denoted as combinations of these terms.

Supplementary Table 3. *P*-values for F tests of time effects and treatment by time interaction effects for ruminal parameters.

	P-value[1]												
Variable	E	D	H	F:D	P:D	F:H	P:H	D:H	F:P:D	F:P:H	F:D:H	P:D:H	F:P:D:H
pH	<0.001	0.45	<0.001	0.73	0.82	0.81	0.06	0.41	0.33	0.54	0.56	0.21	0.42
N components													
NH_3–N (mg/dL)	<0.01	0.81	<0.001	0.41	0.16	0.51	<0.01	<0.001	0.48	0.23	0.07	0.20	0.38
Total AA (mM)	<0.01	0.05	<0.001	0.57	0.20	0.68	0.07	0.02	0.42	0.97	0.08	0.98	0.42
VFA (mM)													
Acetate	<0.001	<0.001	<0.001	0.82	0.97	0.99	0.49	<0.001	0.83	0.50	0.52	0.71	0.87
Propionate	<0.001	0.02	<0.001	0.09	0.50	0.89	0.07	<0.001	0.90	0.54	0.78	0.39	0.91
Butyrate	<0.001	<0.001	<0.001	0.23	0.85	0.90	0.09	<0.001	0.43	0.90	0.63	0.78	0.82
Major VFA	<0.001	<0.001	<0.001	0.48	0.90	0.97	0.26	<0.001	0.81	0.61	0.65	0.65	0.90
Iso-valerate	<0.001	<0.01	<0.001	0.85	0.96	0.85	0.67	<0.001	0.60	0.28	0.87	0.74	0.94
Iso-butyrate	<0.001	<0.01	<0.001	0.62	0.74	0.77	0.33	<0.001	1.00	0.41	0.99	0.89	0.80
Total iso-acid	<0.001	<0.01	<0.001	0.82	1.00	0.86	0.51	<0.001	0.80	0.33	0.92	0.89	0.92

1. Effects for experimental period (E_j, where j = 1, 2, 3, 4), dietary CP level (P_k, where k = LP, HP), CP feeding pattern (F_l, where l = OF, SF), and interactions are denoted as combinations of these terms.



Supplemental Figure 1. Treatment and time effects on the sum of acetate, propionate, and butyrate concentration (Major VFA), ammonia-N concentration, and total amino acid (TAA) concentration. Points and error bars show least squares means ± standard errors (n = 8 cows) for A) Day * Hr,B) CP * Hr, and C) FP*Day*Hr, where shaded rectangles show the daily range of least squares means

CHAPTER 4. LIMITATIONS AND FUTURE RESEARCH

4.1 Literature Review

Our trial used a crossover design and compared two feeding patterns with a modest number of cows. In future work, other experimental and observational research designs could be used to explore the generalizability of our findings. Many existing studies on CP level and feeding pattern used cross-over experiments with brief dietary adaptation periods (2-3 wk, Broderick, 2003; Colmenero and Broderick, 2006). Longer-duration experiments may uncover longer-term effects associated with CP nutrition (Zanton, 2016). For many outcomes of interest (e.g., milk protein yield), it is plausible that the effects of dietary CP are modest when CP is moderate, such that only studies with a greater span in dietary CP, greater sample size, or more reliable measurement and analysis techniques can detect the hypothesized response. With respect to oscillating dietary CP, numerous other feeding patterns have not yet been tested, let alone compared within a single study (Kohler, 2016). Testing other feeding patterns and perhaps imposing controlled but random variation in diet composition over time is a topic for future research.

Both the basal diet and the nutrients substituted for dietary CP may have affected the responses observed in our trial. Oscillating dietary CP requires oscillating the concentrations of other dietary nutrients, and very limited research has described oscillation or infrequent supplementation of nutrients aside from CP. Therefore, additional research could examine the robustness of dietary-CP related findings to a greater variety of CP-substituting-nutrients and basal diets. Our trial lowered dietary CP by replacing it with both fiber and starch, similar to several other studies (Kalscheur et al., 2006; Letelier et al., 2022). In contrast, some reports replaced CP predominantly with either NDF (Barros et al., 2017) or non-fiber carbohydrates

(Colmenero and Broderick, 2006). In a meta-analysis, Souza and White (2021) found with lower-quality diets (higher lignin), a greater portion of recycled urea was returned to the ornithine cycle rather than used for anabolism. In our trial, all basal diets were moderate in starch and fiber content. It is plausible that replacing dietary CP with rumen-fermentable carbohydrates could support greater microbial protein synthesis, altering urea dynamics and enhancing the capture of N for anabolism.

In addition to accounting for the basal diet and nutrient substitutions, the kinetics of protein degradation and interactions with energy nutrition have been underexplored in low-CP and oscillating-CP diets. Recently, Kand and Dickhoefer (2021) reported differences in microbial protein synthesis for lactating cows fed faster- and slower-degrading dominant dietary protein sources (faba bean meal vs. xylase-treated soybean meal, respectively) targeting a negative ruminal N balance. Beyond ruminal effects, Omphalius et al. (2019) recently reported that absorbed energy and protein supplies interacted to influence MP efficiency, which was greatest for the high energy low protein treatment (Omphalius et al., 2019). These studies illustrate that future research on reduced CP diets can consider moderators of NUE such as protein degradation kinetics, microbial incorporation of recycled N, and energy nutrition.

In addition to testing different diet conditions, future work could test low CP and oscillating CP with different animal conditions. It is plausible that tolerances to CP level and CP oscillation differ based on stage of lactation, and early-lactation or primiparous cows may have had different outcomes than the mid-lactation, multiparous cows in our trial. As DIM advance post-peak production, mammary AA demands decline (Law et al., 2009). The animal's frame growth is typically minimal after the 2nd lactation. Under modern production conditions, the mammary represents the largest AA demand, and AA demands for other body functions (e.g., maintenance, gestation) are comparatively smaller and more stable (NASEM, 2021). Additionally, aspects of the animal's physiology that differ across stages of lactation (e.g., body condition, endocrine functioning) may affect responses to dietary CP level and feeding pattern (Letelier et al., 2022). Indeed, some of the most promising findings from CP oscillation studies have involved growing rather than mature animals (Zhang et al., 2021). More research is needed to understand the implications of CP nutrition across the dairy cow's life stages.

Our trial was outcome-oriented rather than mechanistic. Undesirable responses to reduced dietary CP (e.g., lost productivity, lost body reserves, impaired health) have been well-documented. However, more research is needed to clarify the ruminal and postabsorptive mechanisms underlying these effects. There is evidence that insufficient rumen-degradable protein can suppress microbial growth and fermentation activity, potentially cascading to negative effects on apparent nutrient digestibility (Hackmann and Firkins, 2015). Our trial did not measure ruminal nutrient outflows or ruminal pool sizes, which would have provided more information on conditions for fermentation. Our research was premised on the idea that a dairy cow's labile protein reserves afford tolerance to low and variable dietary protein (Swick and Benevenga, 1977). Insufficient supply of metabolizable AA can suppress body protein synthesis and stimulate degradation, impacting available body protein reserves (Raggio et al., 2007; Giallongo et al., 2017; McCabe et al., 2021). In our trial, we assessed body N accretion by difference (residual N) rather than measuring it directly. Recent studies suggested several methods to estimate N accretion, decumulation, and net flux in dairy cattle. Gross changes in skeletal muscle protein can be measured with ultrasounds of longissimus dorsi thickness (McCabe and Boerman, 2020). Cantalapiedra-Hijar et al. (2019) recently proposed a minimally-invasive isotopic dilution method to estimate whole-body protein turnover. Sadri et al. (2023) discussed invasive and less-invasive methods to measure muscle protein synthesis and breakdown. Invasive multi-catheterization procedures and stable isotope infusions can produce direct, absolute measurements. On the other hand, less-invasive quantification of mRNA abundance, protein abundance, or protein activation (e.g., phosphorylation) offers an indirect, relative index of muscle protein synthesis and breakdown. Future work could assess effects of protein nutrition on body protein synthesis, degradation, and net mobilization in various tissues and at the whole-animal level.

Nutrition research traditionally considered AA as substrates for body use, yet AA play an active role in signaling processes in specific tissues and systemically (Arriola Apelo et al., 2014). The effects of AA-related signaling on DMI and milk protein synthesis may be most important from a practical standpoint. For example, reductions in DMI at lower CP can stem from differences in satiety signaling related to circulating AA from dietary and endogenous sources. As summarized by Martineau et al. (2016), certain AA may act as orexigenic (Lys, Met, His) or anorexigenic (Ser, Thr, Tyr) signals and their effects on intake may be more pronounced when MP is deficient. Many studies have implicated branched-chain AA in mTOR pathway signaling associated with milk true protein synthesis and changes in muscle protein reserves. Activation of the mTOR pathway stimulates protein synthesis by facilitating the initiation of translation and inhibits protein degradation by suppressing autophagy and ubiquitination (Zhao et al., 2015). However, the roles of AA in signaling and as substrates are interrelated. For example, Doelman et al. (2015) showed that imbalanced EAA infusions lacking His, Met, or Phe failed to increase milk protein yield over saline infusions for cows fed a basal diet with 11.2% CP, despite increasing mTOR signaling. Other studies have shown tissue-specific effects of AA supplies.

For example, Curtis et al. (2018) and Nichols et al. (2017) found increased phosphorylation of mTOR related proteins in skeletal muscle but not the mammary gland following BCAA and EAA infusions. McFadden et al. (2020) described the integral role of Met in one-carbon metabolism and subsequent effects on inflammation and disease. Other authors (e.g., Ouellet et al., 2014; Giallongo et al., 2017) have reported on the relations of His deficiency to muscle concentrations of storage dipeptides carnosine and anserine and blood hemoglobin concentrations. These studies illustrate that the implications of low dietary protein on major physiological processes have not yet been fully characterized. Therefore, future research could examine how dietary, absorbed, and circulating AA levels affect physiological processes associated with health and productivity.

Animal-level conceptualizations of N utilization are limited because they do not represent farm- , region-, or industry-level metrics. They describe the flows of N compounds directly in and out of the animal's body, ignoring upstream flows (e.g., feed and fertilizer, machinery), downstream flows (e.g., manure storage, milk processing), and herd size or industry size. Many have argued that environmental sustainability is a property of farms, regions, and industries rather than individual animals. According to this perspective, animal-level metrics represent a reductionist approach that can hinder sustainable development (Zegar and Wrzaszcz, 2017). As noted by Wattiaux (2023), increases in industry size have sometimes meant that improvements in the dairy industry environmental footprint corresponded to similar or increasing total environmental outputs at the industry level. Based on process-based modeling, reducing animal-level N outputs, N footprints, and N use efficiencies has the potential to improve farm-level and industry-level environmental impacts (IFSM, 2015). Still, limited research has documented management interventions resulting in reductions in total N environmental impacts at the farm or industry scale (Hristov et al., 2011; Powell and Rotz, 2015; Rotz, 2018). More research is needed to explore relations between animal-level and farm-level N use metrics (Groot et al., 2006). Future interdisciplinary research can contribute to achieving reducing negative N environmental impacts at broader scales. For example, studies on N flows directly associated with the cow could be supplemented with research on manure emission, runoff, and leaching potential via *in vitro* and field experiments (Mulder et al., 2005; Cosgrove et al., 2017). Future work could also consider the environmental impacts associated with feed production in parallel to animal environmental outputs (Wilkinson and Garnsworthy, 2017). There is an urgent need for broader-scope empirical studies to ensure environmental models represent actual conditions.

An alternative conceptualization of N utilization efficiency involves the return of human-valuable nitrogenous outputs per unit of human-undesirable or human-inedible nitrogenous inputs (Wilkinson and Lee, 2018). Many studies (e.g., Rius et al., 2010) refer to lactating dairy cattle as "relatively inefficient" utilizers of dietary N. Indeed, a typical lactating cow may excrete two to three times more N in manure than the amount she secretes in milk (Dijkstra et al., 2013). However, ruminants can utilize non-protein nitrogen and low-quality proteins (i.e., unfavorable AA profile relative to animal demands) to a greater extent than monogastric animals, because rumen microbiota synthesize high-quality protein (NASEM, 2021). As a result, simulation studies have shown that dairy ruminant systems can output more human nutritional value per unit of human-edible input relative to monogastric systems (Wilkinson and Lee, 2018), largely due to the conversion of forage N to milk protein. Future studies could investigate diets for lactating cows that align with alternative metrics of N use efficiency such as human-edible protein efficiency.

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CHAPTER 5. HISTORY AND PROGRESS IN ANIMAL AND DAIRY SCIENCES EDUCATION

5.1 Abstract

Compared with higher education as a whole, animal and dairy science has a unique origin story and utilizes distinct signature pedagogies. Dairy science postsecondary education is transforming in response to emerging industry trends such as consolidation and globalization, and public needs for economic and socially-sustainable production. There is insufficient literature to discuss dairy sciences alone, but animal and dairy sciences education research produces approximately 5 publications per year. Animal and dairy science educators share similarities with postsecondary educators in other life sciences disciplines where instructors are predominantly trained in natural science research methods. However, our field can learn from disciplines such as biology education to ask more student-relevant questions, use more robust methods, and report procedures and findings in greater detail.

5.2 Literature Review

5.2.1 Dairy science education origin story – the land grant directive

Domesticated ruminants have provided humans a source of milk for over 8000 years (Vigne & Helmer, 2007) and universities have existed for the last millenia (Perkin, 2007), yet postsecondary dairy science education is a much more recent phenomenon. In the U.S., dairy science higher education began with a series of congressional acts passed in the late 19th and early 20th century that established land-grant universities and research stations (Table 1). In contrast with higher education focused on religion and liberal arts, public funding of land-grant institutions promoted secular education in agriculture, science, and engineering in response to the industrial revolution (National Research Council [NRC], 1995). The historical perspective also illustrates the deep roots of core issues in dairy science education research. For example, land grant universities enabled greater participation of rural people in higher education and promoted scientific approaches to agriculture. However, dairy sciences programs began amid segregation and discrimination on the basis of gender, race, sexual orientation, and disability.

Picture 5.1 A course at the University of Wisconsin involving cross-bred cattle. Source: https://andysci.wisc.edu

Table 5.1. Timeline of important congressional acts in dairy science post-secondary education history (NRC, 1995).

1862	**First Morrill Act.** Granted federal land to states to create and endow "land grant" colleges focused on agriculture, science, and engineering.
1887	**Hatch Act.** Established agricultural experiment stations connected with each state's land-grant college.
1890	**Second Morrill Act.** Provided states cash to further support land grant universities. Prohibited racial discrimination in admittance to land grant institutions. Amid segregation, this led states to create 19 institutions now referred to as "historically-black colleges and institutions (HBCU)" or "1890 institutions."
1914	**Smith-Lever Act.** Created cooperative extension service to distribute findings of agricultural research to serve the public.

5.2.2 Animal and dairy science philosophies and signature pedagogies

Animal and dairy science has been described as a "hard applied" discipline similar to nursing or engineering, in which scientific theories and findings inform practical decisions and problem-solving (Biglan, 1973; Becher, 1989). Accordingly, animal and dairy science education is more pragmatic than paradigmatic—it prioritizes empirical and problem-based learning over conceptual learning and abstract reasoning (Kensinger & Muller, 2006; Erickson et al., 2020). A priority of undergraduate instructors is to educate animal and dairy science professionals for vocations in industry (Buchanan, 2008). As a consequence, instructors favor hands-on, experiential learning such as laboratories and student-driven projects (Taylor & Kauffman, 1983). Case studies and simulations also figure prominently in teaching students problem-solving (Parrish et al., 2015). Wattiaux (2009) encapsulated the signature pedagogy of animal and dairy science with the example of the capstone course, in which students work collaboratively to translate basic knowledge to application in the context of a realistic problem scenario. Such capstone courses sometimes involve the partnership of local farms and agribusinesses to provide context or serve as external evaluators.

Preparing students for careers as animal and dairy science professionals has remained a central goal of our field. However, as stated by University of Wisconsin dairy scientist Gustav Bohstedt (1933):

> *A college which is aiming to do work of university caliber has basically more important things to do than serving as a trade school.*

Although the precise intent of Bohstedt's statement is unclear, given its context it may reflect the Wisconsin Idea made popular by Van Hise in 1904. In other words, animal and dairy science education should aim not just to develop students as professionals, but also as humans; and not just to serve industry, but also the public. Another early-century animal scientist Trowbridge (1923) similarly stated:

> *Is it not possible for animal husbandry to be so taught as to serve even a greater purpose…to acquaint men [sic] with science, economics, and the humanities; to develop far-seeing, logical thinkers, end citizens whose lives are more satisfactory to them and most useful to the rest of the world…*
> *(from Buchanan, 2008, p. 3641)*

Animal and dairy sciences instructors have approached humanistic learning outcomes in various ways. For example, instructors have involved students in the process of research (Karcher & Trottier, 2014, Jones & Lerner, 2019) and public outreach (Walker, 2011), developed intercultural experiences (Grant et al., 2019) and designed courses based on shared inquiry into current issues (Splan, 2018).

In recent years, learning outcomes in undergraduate programs continue to reflect both professional and humanistic aims. However, since the early 2000s, few animal and dairy science publications have explicitly stated learning outcomes related to civic learning and personal growth (Erickson et al., 2020). Parallel to the ascendance of neoliberal ideologies in higher education and rising tuition costs (Mintz, 2021), the animal and dairy science education literature shows a trend to express learning outcomes in terms of their value to workforce development. Although it is unclear if this trend represents changes in instructional priorities and practices or instead is purely semantic, it seems to mark a shift away from humanistic, liberal goals and toward viewing students as consumers and prospective human capital.

The priorities of modern animal and dairy science education are indeed being pulled in several directions by student, employer, alumni, and government stakeholders. For example, a recent Association of Public and Land-grant Universities report (Crawford & Fink, 2020) asked agriculture stakeholders to rate skills based on their importance and the relative preparedness of agriculture undergraduates. The authors used this information to identify skills with the greatest "importance-preparedness gaps." Among the skills employer respondents rated as the most important and most often lacking were "understand role in the workplace and have realistic career expectations," "accept critique and direction in the workplace," and "listen effectively"--illustrating the employer-respondents' conformist agenda for postsecondary learners! The students surveyed for the same report had drastically different priorities that included building professional relationships and navigating change and ambiguity.

In summary, the current situation in animal and dairy sciences is consistent with other life sciences disciplines where content-learning is a significant focus of postsecondary education, and non-content learning is justified insofar as it contributes to workforce needs (Thompson et al., 2018). In contrast, at the K-12 level, recent funding and efforts dedicated to improving agricultural and scientific literacy may signal some return to humanist, civic educational goals (OECD, 2019; Kovar & Ball, 2013).

5.2.3 Emerging industry and public needs in the dairy sector

Current issues in dairy science postsecondary education stem from efforts to meet emerging needs of a changing dairy industry and global population. In recent decades, consolidation and improvements in productive efficiency have altered the dairy landscape. Likewise, confronting climate change, improving human and animal well-being, and improving diversity and inclusion have become increasingly important shared goals. In some cases, animal and dairy sciences educators have responded by developing curriculum and pedagogy. However, educational gaps remain.

Consolidation and efficiency

From the 1940s to present day, the dairy population reduced from 25.6 million to 9.2 million cows, yet milk yield per cow quadrupled, leading to a net increase in total U.S. milk production (Capper et al., 2009). A modern gallon of milk requires lower inputs of feed, water, and land resources and results in substantially lower manure and greenhouse gas emissions compared with the same volume of milk in 1940 (Figure 2; Capper et al., 2009; USDA NASS, 2021). According to von Keyserlingk et al. (2013), these tremendous improvements in productive efficiency were largely “paid for by economies of scale” (p. 5405). Whereas small farms (<200 cows) held a majority of the U.S. dairy herd as late as the 1990s, today the majority of U.S. dairy cattle live in large herds with >1000 cows (USDA NASS, 2017).

Industrialization and consolidation in the dairy industry have drastically altered the landscape of careers for dairy science graduates (Wattiaux, 2008). Whereas the archetypical dairy science student in the mid-1900s gained general expertise and returned to their family farm, today’s students often desire specialized expertise related to certain topics (health, reproduction, nutrition, genetics, welfare, sustainability, data management) or industry functions (research & development, technical services, sales, marketing, communication, management). The animal and dairy science education literature reflects increasing specialization in these subdisciplines through the development of subdiscipline-specific pedagogies. For example, Johnson et al. (2008) used a computer simulation to teach students about dairy cattle metabolism. Parrish et al. (2015) and Brown and Payne (2017) described teaching methods developed to overcome conceptual hurdles specific to cattle reproduction. These studies were trailblazing advancements, yet they described pedagogies only in terms of their theoretical benefits to students based on instructional design principles. As a result, more research is needed to prove that these subdiscipline-specific pedagogies functioned to produce the intended learning experiences and outcomes.

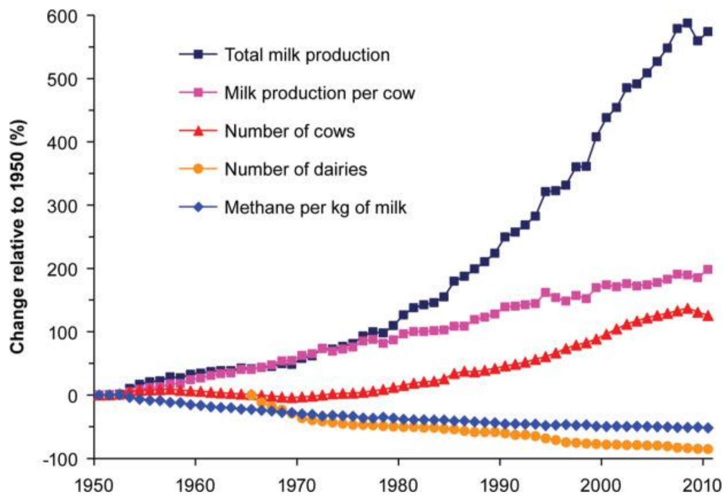

Figure 5.1. Changes relative to 1950 in total milk produced, milk production per cow, total number of dairy cows and dairies, and methane produced per kilogram of milk in the California dairy industry between 1950 and 2010. Note that CA increased cow populations, unlike the U.S. as a whole. Source: von Keyserlingk et al., 2016

Social and interdisciplinary challenges

Although specialization into subdisciplines has become typical practice, the dairy industry is increasingly confronting problems requiring interdisciplinary expertise. For example, the Innovation Center for U.S. Dairy and the National Milk Producers Federation (NMPF, 2021) set industry targets for 2050 including the ambitious goal to achieve greenhouse-gas neutrality on a carbon dioxide equivalent basis. Measuring and improving dairy cattle welfare is another significant industry push. Research has shown the majority of the public report being concerned about dairy cattle welfare although the price of milk also factors into their perceptions of acceptable practices (Wolf et al., 2016; Cardoso et al., 2016). Research has also illuminated needs to support safety, well-being, and mental health of dairy producers and employees (Menger et al., 2016), and to consider the public health implications of dairy practices and products (Prentice, 2014).

These emerging priorities for the dairy industry are not yet reflected in most animal and dairy sciences undergraduate programs or in the corresponding education research literature. For example, of the n = 71 animal and dairy sciences education publications reviewed by Erickson et al. (2020), only two publications explicitly addressed teaching sustainable agriculture (Karcher and Powers., 2013; Splan, 2018), one addressed teaching animal welfare (Arnold et al., 2018), and none addressed teaching about the humans in dairy systems. The lack of literature may reflect that specific courses have not yet been developed and implemented about these topics. As Redmon et al. (2022) pointed out, topics at the margins of animal and dairy science sub-disciplines can “fall between the cracks” such that no discipline area assumes responsibility for teaching them. The authors gave the example of “forages,” a topic related to both plant and dairy sciences as a potential area for developing cross-listed courses co-taught by faculty in each discipline. Using a similar approach, Bott and Cortus (2014) described an agricultural waste management module conducted in collaboration with Equine and Waste Management professionals. These studies suggest that developing teaching and teaching scholarship on emerging social and interdisciplinary topics will require creative and collaborative curriculum development. Three decades ago, Kauffman (1992) suggested that modern animal science curricula could be made more open to other disciplines:

> *Animal [and dairy] science is not losing its identity. On the contrary, it is broadening to include disciplines and species that were not considered in the past. We need to expect continually to have changes in the curriculum as innovative solutions appear and as additional demands and interests are manifested. (p. 2596)*

Kauffman (1992) approached integrating social science and interdisciplinarity as a matter of designing flexible curricular tracks that enable (and encourage) interdisciplinary study while maintaining shared foundational coursework. This suggests research is needed both to establish foundational, indispensable learning outcomes for all students, and to identify unique interdisciplinary curricular tracks that can be formalized to expand student options.

Globalization

The U.S. is a major exporter of milk with 16% of milk solids exported annually (OECD/FAO, 2020). Whereas demand for dairy products is expected to remain stable in North America and Europe, increased demand in other parts of the world (e.g., Southeast Asia) is expected to drive dramatic dairy expansion in these regions in future years. As a result, the dairy industry increasingly requires practitioners with intercultural competence—in other words, the ability to function and communicate across cultures (Deardorff, 2011). Chang et al. (2013) recognized that most animal and dairy sciences students have no or limited international experience and report facing financial barriers to participation in study abroad. Especially pre- and post-college, responsibilities for daily animal care may also limit animal and dairy sciences students' ability to travel internationally. As such, undergraduate animal and dairy sciences programs have invested significant effort in short-term study abroad programs. For example, Bott-Knutson et al. (2019) described a two-week long *China Ag* experience exposing students to dairy production in Asia and assessing changes in their beliefs about U.S. and Asian agriculture. Other authors have paired international exposure with preparation and debriefing activities specifically designed to improve intercultural competence. For example, Grant et al. (2019) used the Intercultural Development Inventory and literature-supported peri-travel activities to document improvements in intercultural competence in upper-level animal science students associated with a trip to Vietnam. For their part, Wattiaux and Crump (2013) documented changes in students' self-reported learning gains and worldviews in a discussion-driven international livestock agriculture classroom taught a as a prerequisite to study abroad. Erickson et al. (2020) reported a significant increase in animal and dairy science education research assessing study abroad programs since 2008, however, more research can clarify the optimal program designs to produce improvements along specific intercultural development stages.

Diversity and inclusion

Since its inception, dairy science postsecondary education has served the needs of the dairy industry and its constituents. Compared with other undergraduate life sciences disciplines, dairy science has been slower to improve diversity and inclusion. This is likely related to structural inertia in ownership of agricultural land and animals in the dairy industry. For example, 98% of agricultural land area in the U.S. is owned by white people (USDA NASS, 2017). Most dairy producers are men (70%), and woman producers most often co-operate farms with men rather than exercising sole decision-making power. Recent data show that only 4.1% of dairy operations have a woman principal operator (Figure 2), making the dairy industry one of the least woman-operated agricultural sectors (USDA ERS, 2019). Immigrants, especially Latinx, comprise a large fraction of the dairy workforce in the U.S., and the limited research describing their experience has in some cases illuminated problems with workplace discrimination (Menger et al., 2016).

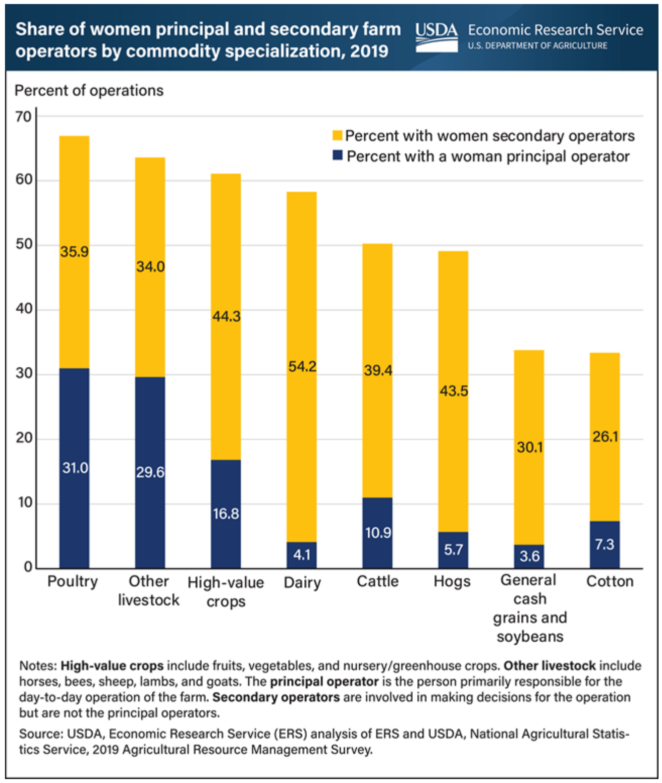

Figure 5.2. Share of women principal and secondary farm operators by commodity specialization, 2019. Source: USDA, Economic Research Service.

Among higher education, agriculture remains one of the least racially and ethnically diverse fields of study surveyed by Integrated Postsecondary Education Data System (IPEDS, 2019) with 76.3% of bachelor's degrees conferred to people self-describing as white. In 2019, many dairy science bachelor's degrees were awarded to women (66.4%), and degree recipients overwhelmingly identified as white (87.2%; IPEDS, 2019). Moving forward, supporting the diversity of degree recipients may be a crucial way to improve the equity and inclusivity of the dairy industry as a whole.

In the animal and dairy science education literature, many authors have observed and commented on changes in undergraduate demographics. Notably, authors have commented on increases in the fractions of undergraduate animal and dairy science students who identify as women, who originate from urban or suburban backgrounds, and who have limited prior experience with food animals (Peffer, 2010; Southworth, 2014; Erickson et al., 2019). Parrish et al. (2015) summarized demographics of the animal sciences programs at several land-grant universities, finding 73-85% of students identified as women and 2-34% reported having an agricultural background. Similar to Casey and Plaut (2010), Parrish et al. (2015) pointed out the mismatch between faculty (predominantly men with agricultural background) and undergraduates (predominantly women without agricultural background).

In other science, technology, engineering, and mathematics (STEM) education disciplines such as biology education, literature has proliferated describing the experiences of students from underrepresented and historically-excluded groups (Briggs, 2017). In contrast, research on racial/ethnic diversity, first-generation college attendees, and the experiences of lesbian, gay, bisexual, transgender, queer, and questioning (LGBTQ+) undergraduates is conspicuously absent from the animal and dairy science literature (Erickson et al., 2020; Elliott-Engel et al., 2019). Considering the race/ethnicity and gender identity demographics reported in several recent studies (Peffer, 2010; Erickson et al., 2019), the lack of diversity itself may limit quantitative research due to low statistical power and the need to protect the identifiability of participants' responses. It is also possible that animal sciences instructors do not consider these research areas a priority (Schillo, 1998). In either case, more research is needed to center and consider the educational experiences related to various student identities.

Additionally, existing animal and dairy science literature has promoted a passive, descriptive approach to diversity and inclusion. For example, researchers related animal and dairy science students' gender and background experience in agriculture with their course performance, critical thinking skills, and interests (Bundy et al., 2019; Mastellar et al., 2019). However, these studies frame demographic differences as naturally-occurring phenomena and fall short of recommending specific interventions, pedagogical actions, and policies to improve outcomes for underrepresented students (Briggs, 2017; Estrada et al., 2016; Theobald et al., 2020). Compared with education research in other STEM disciplines, animal and dairy science education research reflects an uncritical attitude toward the role of postsecondary teachers in structural discrimination and social change.

5.2.4 Animal and dairy science educators

A critically important feature of animal and dairy science education is the use of scientists as educators and higher education administrators. Historically, animal and dairy science postsecondary educators were first and foremost scientists (Taylor & Kauffman, 1983). Despite trends toward adjunctification and specialization in higher education, many recent post-secondary dairy science educators reported past or continued involvement in dairy science as a field of research (Erickson et al., 2020). As Lattuca & Pollard (2016) theorized in a literature review, involving scientists in education affects teaching practices by shaping individual faculty (e.g., their identity, priorities, and beliefs) and departments (e.g., incentives, support systems). Minimal research has described the training and socialization of animal and dairy sciences instructors, and this represents an area for future research.

Current teaching practices

With regard to instructors' training and academic socialization, animal and dairy sciences education faces similar issues as other STEM disciplines in promoting effective, evidence-based teaching. Pre-pandemic course observations showed that instructors in STEM disciplines used teacher-centered strategies such as lecturing for the majority of course time. Animal and dairy sciences instructors appear similar. Self-reported course time usage for 10 animal and dairy sciences instructors during the pandemic suggested that lecture-based teaching predominated (Erickson et al., 2021). Although lecture-based instruction has historical precedent as the dominant teaching mode in science and dairy science (Taylor & Kauffman, 1983), evidence suggests that active learning strategies result in improved student performance, motivation, and retention relative to lecture (Freeman et al., 2014). Active learning is widely reported on in animal and dairy sciences teaching scholarship (Erickson et al., 2020). Although it may be common among instructors engaging in teaching scholarship, it likely is not yet the norm across all instructors. Assessing instructor awareness and use of various instructional practices through surveys and classroom observation represents a significant opportunity for future research.

Assessing and promoting teaching excellence

In general, there appears to be a lack of consensus among animal and dairy sciences instructors regarding teaching excellence. For example, a survey of 90 teaching-interested animal and dairy sciences instructors showed that most reported attending teaching-related professional development events regularly, using student feedback to improve their courses, and discussing teaching-related issues in meetings with colleagues (Erickson et al., 2020). However, a survey of 50 animal and dairy sciences instructors in 2005 revealed diverse opinions regarding the types of evidence that should be used to document and promote teaching excellence (Wattiaux et al., 2010). Most (79%) of respondents reported that authoring peer-reviewed publications was used to evaluate teaching in their department, but a lesser fraction (51%) felt it should be used. Other forms of teaching scholarship such as abstracts and invited presentations were reported to be less frequently used (55%, 60%, respectively) although over half of respondents indicated that they should be used (55%, 58%; Wattiaux et al., 2010). These findings illustrate that animal and dairy science instructors use local mechanisms to collect informal evidence to improve their teaching practice but may not find it important to create or engage with formal education research. Future research could identify opportunities to incentivize scholarly teaching in our field, given the barriers to participation.

5.3 References

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CHAPTER 6. ANIMAL SCIENCES UNDERGRADUATE EDUCATION SINCE THE ASAS CENTENNIAL: A NATIONAL SURVEY AND SCOPING REVIEW

Citation:
Erickson, M., Ranathunga, S., & Wattiaux, M. (2020). Animal sciences undergraduate education since the ASAS centennial: A national survey and scoping review. *Translational Animal Science*, *4*(4), txaa202. https://doi.org/10.1093/tas/txaa202

6.1 Abstract

The rapid pace of advancement in animal sciences is drastically changing conditions for undergraduate teaching and learning in the discipline. Shortly after the American Society of Animal Science (ASAS) centennial, we conducted a national survey of 90 faculty instructors from 49 academic institutions to assess their perceptions of emerging teaching topics. Participants rated 18 learning outcomes (LO) and 16 types of courses and experiences (CE) with respect to their importance and the adequacy of available offerings. This study presents the results of the survey along with a scoping review of animal sciences teaching and learning publications since 2008 (n = 71). Results indicated that discipline-specific competencies and core experiential learning remain central to animal sciences teaching and identified several distinct needs for research. Namely, we suggest that future research in animal sciences teaching and learning 1) develop animal-science-specific expertise on a greater variety of pedagogies, 2) validate improved methods for assessing transferable skills, 3) expand pedagogical knowledge of emerging topics (e.g., sustainability, data science, welfare science, social science), and 4) deepen and broaden animal sciences' teaching and learning identity through theory-building work and collaborations across instructors, disciplines, and institutions.

Keywords: animal science, experiential learning, pedagogy, teaching, undergraduate

6.2 Introduction

In an American Society of Animal sciences (ASAS) centennial review of animal sciences teaching, Buchanan (2008) called for no less than a nationwide re-evaluation of the learning outcomes, course experiences, and assessment programs in animal sciences undergraduate programs. The conditions for teaching and learning animal sciences have changed so drastically, he argues, that departments must update teaching practices or risk becoming obsolete (Thaxton, 2003; Buchanan, 2008). Indeed, attitudes surrounding animal care and use are shifting and food production systems are becoming more complex (Meyer, 1993). Practitioners of animal sciences now occupy a more biotechnological, global, and multicultural space than ever before (Britt et al., 2008). Likewise, today's undergraduate animal sciences enrollees have dramatically different interests, goals, and backgrounds than students of past decades (Edwards, 1986; Peffer, 2010; Reiling et al., 2003).

In response to changing needs, departments of animal sciences must continually engage in relevant teaching practices and assessment relying on discipline-based educational research (DBER), reflective practices, and scholarship of teaching (SoTL; Kreber, 2002; McNamara, 2009; National Academies of Sciences, Engineering, and Medicine, 2018). During most of the 20th century, professional development opportunities in animal sciences were limited to symposia and informal interactions— for the most part escaping empirical analysis, rigorous peer scrutiny, and archival in journals (Buchanan, 2008). The lack of an adequate peer-review process slowed progress substantially. Only recently, as departments of animal sciences renegotiate the distinct public role they serve, has scholarly understanding of undergraduate education in the discipline begun to develop (Kezar, 2004; Buchanan, 2008). As more and more instructors combined their research and teaching acumen to address SoTL and DBER topics, the volume of research has grown substantially. However, most of the research thus far is situated within a single classroom, instructor, and/or institution. To our knowledge, no prior work has systematically described emerging practices in animal sciences teaching and learning at a broader level, across universities and within the burgeoning scholarly literature. The objectives of our research were consequently to:

1) describe U.S. faculty instructors' views of learning outcomes (LO) and course experiences (CE) with respect to their importance and the adequacy of available offerings in their current program.
2) Quantify the volume of research on specific LO and CE themes through a scoping review of publications on teaching and learning in animal sciences since the ASAS centennial (2008-2020).

6.3 Materials and Methods

6.3.1 Survey Administration and Instrumentation

All survey procedures were approved by the Institutional Review Board. A research team of experienced instructors created a quantitative questionnaire including LO and CE frequently mentioned by colleagues, in the literature, and at conferences (Appendix 1). After beta testing and refining the survey with a small sample, researchers administered the survey instrument in paper form during two conferences: The National Conference on Teaching and Learning in the Animal Sciences, University of Wisconsin, Madison, WI in June, 2012, and the Teaching Workshop at the American Dairy Science Association-American Society of Animal sciences Joint Annual Meeting, Indianapolis, Indiana in July 2013.

The anonymous survey included five sections. In section 1, participants rated the importance of a list of 18 LO on an anchored scale of 1 (not important at all) to 5 (a great deal of importance) and the adequacy of each LO in their current academic program on a scale of "good as it is," "need more," "no opinion," and "need less." Section 2 used the same scoring scales to assess the importance and adequacy of 16 CE. Topics assessed through sections 3 and 4 included basic information on participants' teaching experience and teaching in their department. Finally, section 5 evaluated institutional and professional demographics.

6.3.2 Survey Participants

148 participants completed the survey; 79 in 2012 and 69 in 2013 (Table 1). For the 14 participants who repeated the survey in 2013, we found no statistical differences between 2012 and 2013 responses and subsequently retained only 2013 values. Because our focus was on faculty members from U.S., we excluded responses representing faculty from foreign universities [n =22], academic staff members [n =9], post-doctoral research associates [n =2], graduate students [n =6], and other professionals [n =1]. We further excluded several incomplete responses [n = 4]. The final dataset included 90 professors from 49 animal and dairy science departments from 38 U.S. states (AL, AZ, CT, FL, GA, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MS, MT, NC, ND, NE, NH, NV, NY, OH, OK, PA, SD, TN, TX, UT, VA, VT, WA, WI, WV, and WY). The majority of respondents (85.6%, N = 77) represented research-focused doctoral institutions (Carnegie Basic Classification 15 or 16). Participants reported a median of 40% teaching appointment (IQR = 25, 70), 20% research appointment (IQR = 0, 50), 0% extension appointment (IQR = 0, 0), and 0% administrative (IQR = 0, 19) appointments.

6.3.3 Survey Statistical Analysis

We conducted all analyses in SAS (v.9.4, SAS Institute, Inc., Cary, NC) and created visualizations in R (R Core Team, 2019). First, we computed descriptive statistics for participants' demographic data, the perceived importance of LO and CE, perceptions of teaching and learning in their departments, and perceived adequacy of LO and CE in the participants' academic programs. Next, we began dimensionality reduction for the 18-item LO and 16-item CE questionnaires. We verified sampling adequacy through the Kaiser-Meyer-Olkin (KMO) statistic (0.80 and 0.64 for LO and CE, respectively). Then, we conducted a principal component analysis (PCA) on responses to each questionnaire using the PROC FACTOR procedure. Using the Kaiser criterion (eigenvalue > 1), we retained four PC explaining 66% of the variance in LO responses and five PC accounting for 67% of variance in CE responses (Stevens, 2002). We excluded four items on the LO questionnaire and two items on the CE questionnaire due to low communality (<0.49). Each set of extracted factors underwent varimax rotation to enhance the interpretability of the principal components (PC). Finally, we calculated Spearman correlations among PC scores of LO and CE in our sample using the PROC CORR procedure of SAS.

6.3.4 Scoping Review and Coding Methods

To integrate recent scholarly literature into our analysis, we conducted a scoping review of articles on teaching and learning in animal sciences and applied LO and CE categories discovered through our PCA as *a priori* themes for provisional coding (Saldaña, 2009). Our search identified 71 relevant full-text articles published between 01/01/2008 and 05/01/2020. Detailed information on our scoping review and qualitative methods is available in the supplemental material accompanying this article.

6.4 Results and Discussion

6.4.1 Institutional and Professional Demographics of Survey Participants

Table 1 describes the professional demographics of the 90 U.S. animal sciences faculty survey respondents. The sample appeared balanced in their self-descriptions of gender and professorial rank, however, a large majority described their race as “white.” Most participants were born in the U.S. and many completed both undergraduate and graduate degrees domestically. Many indicated being the first generation in their family to attend college. Figure 1 shows participant beliefs and practices related to their own teaching. Most participants indicated that they currently prioritized teaching in their career and believed themselves to have been successful in teaching. To a lesser extent, participants reported prioritizing administration, research, and extension in their careers. Most instructors expressed an interest in improving their teaching and many reported regular attendance at teaching-related programs. Roughly half of participants believed their classes to be student-centered, although a majority of participants claimed to use student feedback in course improvement efforts.

Very little past research has described the demographic profile of U.S. animal sciences faculty. Compared with Casey and Plaut’s (2003) national survey of ADSA/ASAS members, our sample showed a similar lack of racial/ethnic diversity but greater apparent balance across genders. Despite persisting structural barriers and demographic inertia, the participation of diverse gender, racial, and ethnic groups appears to be slowly increasing among agricultural science academics (NCSES, 2018). The large fraction of women in our sample may also be attributable to the relatively greater contribution of women to teaching and service activities (Guarino and Border, 2017), especially at research institutions (Singell et al., 1996). Animal sciences's traditional values—criticized as androcentric, individualistic, and overly-focused on economic efficiency—continue to bias the professional reward structure against diversity (Schillo, 1998; Wattiaux, 2010).

Although our participants overwhelmingly represented research-active doctoral institutions, their responses demonstrated a clear focus on teaching and scholarly teaching across a wide range of declared appointments. Administering surveys at teaching events at scientific conferences may likely have selected for this type of respondent. Still, across institutional types and disciplines, faculty on average spend the majority of their working time on teaching-related tasks (FSSE, 2010), though they differ in their commitment to scholarly teaching (Richlin, 2001). Indeed, research has shown that instructor attitudes and beliefs surrounding teaching are stronger predictors of their use of student-centered practices than institutional or professional factors (i.e. class size, teaching appointment, institution type; Yoder, 2019). The majority of our participants reported engaging in some scholarly teaching activities such as discussing teaching with colleagues, utilizing learner-centered teaching methods, and incorporating student feedback. However, we did not assess their teaching practices, professional development, or engagement in teaching research in great depth.

6.4.2 Instructor Ratings of the Importance and Adequacy of Learning Outcomes

Table 2 displays eigenvalues and variance explained for selected principal components of the importance of LO. Principal component analysis identified 4 PC for the importance of LO which we termed practical agribusiness competencies (LO-1), analytical, collaborative skills (LO-2), multi-modal communication skills (LO-3) and discipline-specific competencies (LO-4) based on the common characteristics of items on each PC (Table 3). Figure 2 summarizes instructor perceptions of the importance of LO and the adequacy of teaching with respect to LO at their institution.

Multi-modal communication skills were rated among the most important, yet the majority of instructors described the teaching of these LO as adequate at their institutions. In contrast, discipline-specific competencies were rated both as highly important and greatly in need at animal sciences teaching institutions. Instructors uniformly agreed that analytical, collaborative skills are important. However, in many cases, they felt that their institutions currently taught such skills at an acceptable level. Finally, instructors diverged on their perceptions of the importance and adequacy of practical agribusiness competencies, the principal component explaining the greatest amount of variance. Instructors rated agricultural policies, language skills, and intercultural competence as a relatively important skill, however, issues related to international agriculture appeared to be less favored.

More and more research has called attention to the importance of communication, interpersonal, and practical business skills in life science (Schillo, 1997; Fischhoff, 2013). Such skills, i.e., transferable skills, are among the most sought-after by agricultural and natural resources industry leaders (Easterly et al., 2017), and employers report that recent graduates are only “somewhat” prepared by undergraduate degrees (Alston et al., 2009). In animal sciences, signature pedagogies such as judging competitions, quadrathlons, and other industry-partnered events are common means to integrate development of transferable and scientific skills (Wattiaux, 2009; Kauffman, 1992). Similarly, the increasing popularity of active, learner-centered methods in animal sciences has positive implications for implicitly developing transferable skills (Yamada, 2018; Erickson et al., 2020). Still, few undergraduate scientific curricula target and assess these learning objectives explicitly through required coursework

(Brownell et al., 2013). In the absence of curricular integration of transferable skills in animal sciences, our instructors' mixed ratings on the importance and adequacy of LO-1 and LO-3 may reflect varying evaluative frames of reference. Greater integration of communication, interpersonal, and practical skills into required courses and more rigorous assessment (e.g., the use of portfolio evidence) may assist departments of animal sciences in understanding and improving student outcomes in this area (Rees and Sheard, 2004; Williams et al., 2002).

Scientific faculty uniformly value discipline-specific competencies and analytical skills and our respondents appeared no different (Stedman and Adams, 2010). While employers emphasize broad, flexible analytical skills, however, many science faculty focus primarily on delivering adequate content—viewing teaching scientific process skills (i.e., the analytical, self-regulatory, collaborative aspects of science) as beyond their responsibilities or abilities (Coil et al., 2010; NRC, 2011). This may explain why our respondents rated both LO-2 and LO-4 items as highly important but emphasized teaching needs for content-focused discipline-specific competencies. Alternatively, the pace of advancement in animal sciences may necessitate more focus on developing pedagogical content knowledge for new technologies and ideas (Hill et al., 2008; Kauffman, 1992). Considering the unique expertise of faculty in making instructional decisions along with the needs of students and employers through more research is warranted.

6.4.3 Scoping Review of Learning Outcomes in Recent Literature

The results of our scoping review (Figure 4) showed a distinct focus on assessing discipline-specific competencies (LO-4) and relatively fewer publications addressing practical agribusiness competencies (LO-1), analytical, collaborative skills (LO-2), multimodal communication skills (LO-3). Researchers were steadfast in assessing discipline-specific competencies (LO-4) throughout our timeframe, whereas research assessing other learning objectives appeared more sporadic. A wide range of courses and student types were represented within each LO, indicating that researchers considered these outcomes relatively non-specific. Publications often addressed several LO in tandem (n = 62).

The focus on discipline-specific competencies (LO-4) is unsurprising given that these skills have the longest tradition of educational measurement in our discipline (Taylor and Kauffman, 1983). Most papers, even those focused on unrelated skills, included a measure of discipline-specific competencies. This may be due to the ease of assessing such skills. Most animal sciences professors regularly assess discipline-specific competencies through quizzes and tests recorded in a gradebook. Because faculty hiring practices favor discipline-specific expertise (Wattiaux, 2010; NRC, 2011), instructors are skilled at identifying salient concepts and constructing suitable assessments. Further, instructors likely receive more support for investigating discipline-specific skills because the academic socialization of non-teaching colleagues and administrators inclines them to value content skills (Lortie, 1975). Whether or not the large volume of research assessing discipline-specific competencies translates into higher quality teaching offerings has yet to be determined.

Conversely, practical agribusiness competencies, analytical and collaborative skills, and communication skills are newer to formal animal sciences education (Haug, 1996; Aaron, 1996; Orr, 1996). Agriculture faculty are less competent at teaching and assessing non-content skills and rarely include them in regular assessment, making them less accessible as a measured variable (Burbach, 2012; Blickenstaff et al., 2015). According to Blickenstaff et al. (2015), faculty in colleges of agriculture report lack of time, lack of resources, and lack of emphasis on teaching in the promotion and tenure process as the top three barriers to improving their teaching. Our scoping review indicates that many animal sciences faculty, faced with these constraints, are unable to develop the expertise and programmatic focus necessary to assess non-content skills. To make progress in adequately teaching these skills, departments of animal sciences need to explicitly value these broader transferable competencies: in the curriculum, in promotion and tenure decisions, and in allocating resources (Wattiaux, 2010). Until then, partnerships with campus instructional resource centers, school of education faculty, or other expert collaborators may assist instructors in assessing valued skills (e.g.,Erickson et al., 2019a; Karcher et al., 2013). Given the importance ascribed to such skills by the experienced instructors in our sample (especially LO-3, LO-2), greater research is warranted on teaching these skills in undergraduate animal sciences in the coming decades.

6.4.4 Instructor Ratings of the Importance and Adequacy of Courses and Experiences

Table 2 displays eigenvalues and variance explained for selected principal components of the importance of CE. We identified and subsequently named five PC for the importance of CE: core experiential learning (CE-1), internet-based learning (CE-2), community-integrated learning (CE-3), global and research experiences (CE-4), and lecture-based and capstone courses (CE-5; Table 4). Figure 3 summarizes instructor perceptions of the importance of CE and the adequacy of teaching with respect to CE at their institution.

Instructor ratings of the importance of CE showed a great deal more variation within PC than ratings of the importance of LO. For example, CE-1 explained the greatest degree of variation among instructors, yet on average was rated most highly important and most needed. Instructors uniformly supported hands-on laboratories and internships as a teaching modality but varied more substantially in the value ascribed to other experiential activities. Most instructors rated internet-based learning (CE-2) as highly important and needed, with a small fraction of dissenters driving apparent variation. Community-integrated learning (CE-3) through real-world, project-based activities appeared more important to instructors than service learning, although curricular offerings for service learning appeared to be in greater need. Regarding CE-5, instructors rated capstone learning highly important but adequately taught at their institutions. Powerpoint-based lectures—the most contentious CE topic—split instructors regarding both importance and adequacy of teaching (Figure 3). In our sample, instructor ratings of the importance of lecture-based learning were correlated with their views on capstone learning such that the two items composed a single principal component. This principal component (CE-5), which explained a relatively small amount of variance, represents a possibly artifactual finding due to PCA's assumption that the totality of variance is explained by components rather than partitioned into that explained by latent structures and that of unique error, as in factor analysis (Kaplan, 2009). Similarly, global and research experiences (CE-4) also appears to encompass a greater apparent variety in topics. On average, instructors rated CE-4 as important, but in many cases felt their institutions provided adequate teaching.

Hands-on, experiential learning has been the backbone of animal sciences pedagogy for over a century (CE-1, CE-3; Buchanan, 2008; Wattiaux, 2008). Practical needs have driven and organized learning across the diverse topics composing our discipline historically (e.g., genetics, nutrition, economics, agronomy) and accommodated emerging topics that promise to revolutionize the discipline (e.g.,sustainability, data and computer science; McNamara, 2009; Erickson et al., 2020). Experiential learning in animal sciences will undoubtedly continue to evolve in the future. As demographics and funding sources change, many animal sciences departments are expanding offerings to provide continuing education and serve non-traditional student groups (e.g., placebound learners) through flexible online courses (Britt et al., 2009; McNamara, 2009). The demographics of traditional students are also shifting. Contemporary aspiring animal scientists are more diverse, more computer-savvy, and have less prior animal experience than students in past decades (Britt et al., 2009; Peffer and Ottobre, 2011). Our results indicate that many institutions, possibly through a large volume of teaching research, may be adequately updating experiential pedagogies to encompass these changing student needs and goals.

Powerpoint-based lectures have been the subject of much scrutiny as an animal sciences teaching modality (Mortensen and Nicholson, 2015; Erickson et al., 2020). Today's Powerpoint-aided lectures have strong historic roots—evolving from spoken-word and chalkboard presentations (Armour et al., 2016). Early departments of animal sciences, wrought from an industrial model of education, used lectures to disseminate information efficiently across large groups of students. Didactic lectures still enjoy widespread use in today's animal sciences undergraduate programs (Balschweid et al., 2014), although a great deal of research discredits their effectiveness at developing desired skills (Freeman, 2014; Wieman, 2014). In our analysis, Powerpoint-based lectures polarized instructors. Additional research is needed to understand instructors' motivations for choosing didactic lecturing and the preparation and support they receive for implementing lecture alternatives. Hybrid pedagogies such as active lecturing show promise as low-input strategies that can ease the transition to more learner-centered, effective instruction (Bernstein, 2018).

6.4.5 Scoping Review of Courses and Experiences in Recent Literature

Summary results for our scoping review of CE are presented in Figure 4. Results showed a defined focus on studies examining core experiential learning (CE-1) Relatively few publications assessed other forms of CE, although the number of publications within each category appeared to grow over the timeframe assessed. Studies often represented more than one CE (n = 59), and a range of LO were represented across each CE category.

The great volume of research on core experiential learning (CE-1) likely reflects its breadth: CE-1 is a broad category that not only applies to a wide range of animal sciences instructors and courses, but also has historic importance as a signature pedagogy (Wattiaux, 2009). Resurging interest in active learning for higher education during the early 21st century likely also contributed to the research volume by boosting interest and institutional resources for exploring experiential learning topics. Research on CE-1 in our scoping review examined debates (e.g.,Roucan-Kane et al., 2013), team-based learning (e.g.,Hazel et al., 2013), flipped classroom discussion-based learning (e.g.,Wattiaux, and Crump, 2013; Arnold et al., 2018), Problem-based learning (e.g.,Erickson et al., 2019a), learning through hands-on laboratories (e.g.,Bundy et al., 2019; Erickson et al., 2020), and university-guided internship programs (Peffer, 2012; Anderson, 2015). Instructors used experiential pedagogies across a wide variety of courses: from traditional courses in animal handling (e.g.,Bobeck et al., 2013), to courses assessing emerging issues such as sustainability and international agriculture (Wattiaux and Crump, 2013; Grant et al., 2019).

Few publications made explicit reference to lecture-based and capstone learning (CE-5), although these are also popular strategies. The majority of science instructors—even those who use some active learning techniques—use lecture for a large fraction of class time (Stains et al., 2018). Given its widespread use and documented shortcomings, it is possible that instructors regard lecture-based learning as an implicit baseline and consequently make little mention of it in their scholarly publications (Mortensen and Nicholson, 2015; Erickson et al., 2020). It is possible that further research could enhance the quality of lectures as an instructional format. Jones (2010) and others have made the case that "good" lectures remain a valuable aspect of any teacher's toolbox. Efforts to improve lecture-based learning, however, typically center on replacing a fraction of lecture time with more collaborative, experiential strategies (Erickson et al., 2019a). Thus, future research considering the interaction between lecturing and experiential pedagogies may be more useful than that assessing lecture alone.

Capstone experiences, which offer a culminating learning opportunity focused on integrative and practical skills, first emerged as an undergraduate animal sciences pedagogy during the late 20th century and are thus a relatively newer teaching strategy than didactic lecturing (Swanson, 1999; Nilsson and Fulton, 2002). Although capstone experiences can presumably include instructional modalities such as internships, research, study abroad, independent study, service learning, or collaborative courses, limited literature has characterized typical features of capstone courses in animal sciences (Hall and Wood, 2017). Capstone courses have great potential not only as a positive learning experience for students, but also as a means to assess key curricular outcomes through final projects or portfolios (Nilsson and Fulton, 2002). However, publications in our scoping review focused exclusively on student perceptions and satisfaction (e.g.,Hall and Wood, 2017), circumventing questions related to skill assessment. Increasing the impacts of future research on capstone courses will likely require overcoming limitations similar to those described for LO-2 and LO-3: namely, finding the time, resources, and expertise needed to create and assess complex learning experiences.

The remaining less-researched topics, internet-based learning (CE-2), community-integrated learning (CE-3), and global and research experiences (CE-4), apply to a narrower range of courses and instructors compared with core experiential learning (CE-1) and lecture-based and capstone learning (CE-5), decreasing opportunities for research. The scarcity of published literature indicates that animal scientists, collectively, have limited contextual understanding of these teaching formats. Given the potential these CE hold for modernizing animal sciences teaching and developing valued skills (e.g.,analytical thinking, intercultural competence, digital literacy), greater support for developing these CE is warranted (NRC, 2011). Because animal sciences teaching research has for so long existed in the margins, even small organized efforts can improve research productivity. For example, the noticeable increase in research on CE-4 during 2019 seems to be due in part to manuscripts solicited by NACTA for a special issue on global agriculture. No other special circumstances affected the results of our scoping review to our knowledge.

Internet-based learning (CE-2) promises to transform many of the unique challenges faced by animal sciences programs, as publications in our scoping review demonstrate. For example, online simulations could alleviate certain animal welfare concerns associated with training inexperienced animal scientists on handling and management techniques (e.g.,Pulec et al., 2016). Virtual tours can allow larger groups of students to access facilities that geographical distance, safety concerns, or biosecurity concerns had previously rendered beyond reach (outside of review see Erickson et al., 2019b). Computer-generated visualizations of complex structures or physiological processes could enhance their comprehensibility to students (e.g., Johnson et al., 2008; Bing et al., 2011; Oki et al., 2014). The internet also makes an excellent medium for supplemental study tools (e.g., Bing et al., 2011; Maiga et al., 2013; Stewart et al., 2011). The early efforts observed in our scoping review show that online learning can be effective in animal sciences courses, but the full benefits of technology-integrated learning are likely still to be realized by future researchers and teachers.

Community-integrated learning (CE-3), long a critical part of animal sciences extracurricular activities, has only more recently been integrated into required coursework. Service learning and real-world, project-based activities are promising strategies for improving university relations, meeting student needs for personal development, and providing a microcosm for practicing career-relevant skills (Feldpausch et al., 2019). For example, authors in our scoping review implemented community-integrated learning to achieve a variety of ends. Amstutz and colleagues (2010) involved students in political action projects in which teams created voter education resources on contentious issues in animal agriculture. As a result of this program, students reported greater understanding of the topics and greater civic engagement. In Brown and Payne (2017), students worked with local extension services to offer cattle artificial insemination clinics for high school students, with students reporting improved oral and written communication skills and understanding of core topics. Chang et al. (2018) suggested that animal sciences students might prefer study abroad programs incorporating service-learning components. Service-learning may also provide a real-world context for transdisciplinary, trans-institutional, or industry-partnered work (Splan et al., 2018; Karcher et al., 2018).

Global and research experiences (CE-4) are two formative aspects of undergraduate life. For many students, experiences internationally or with research during college may be their greatest exposure to these areas throughout their lives. Intentionally-designed, well-researched programs are thus vital to ensuring that such programs maximize positive outcomes and effectively meet the goals of the undergraduate curriculum. With respect to global experiences, recent publications in our scoping review showed a distinct focus on developing programs with shorter time spent abroad and greater effort expended at the home campus through pre- and/or post-coursework (e.g.,Karcher et al., 2013; Bott-Knutson et al., 2019). Educators report that short-term (1-3 week) in-country visits can produce similar gains in intercultural competence at a lower cost to students (Chang et al., 2018). More recent publications showed progress toward more valid mixed-methods assessment of intercultural competence (e.g.,Grant and Karcher, 2019), novel topics such as sustainability (Karcher et al., 2013), and novel synergies with learning communities, the extension system, and industry partners (Grant and Karcher, 2019; Chang et al., 2018). The existing body of research appears limited by the small number of publications and small number of programs assessed.

Our scoping review also showed positive developments in undergraduate research programs. Karcher and Trottier (2014) documented that a club science research project improved students' integration into the animal sciences community and their understanding of the scientific process. Jones and Lerner (2019) found that undergraduate research experiences significantly improved students' critical thinking skills. In particular, course-based undergraduate research experiences (CUREs) may be critical to improving equity and diversity in scientific fields (Hernandez et al., 2013). Compared with traditional independent, student-directed undergraduate research, CUREs overcome numerous structural barriers that serve to re-inscribe hegemonic order and perpetuate inequities – including limited research opportunities, unconscious bias, financial and personal barriers, and conflicting cultural norms (Carlone and Johnson, 2007; Bangera and Brownell, 2017). Jones and Lerner (2019) observed gains in critical thinking ability for animal sciences students involved in CUREs versus those completing undergraduate research in the traditional format. Outside of our scoping review, Bangera and Brownell (2017) make a strong case that CUREs should be required for all life science students, and Ballen and colleagues (2017) describe broad benefits of involving non-majors in CUREs. Besides helping students, enhancing the quality of undergraduate research programs has implications for improving the productivity and well-being of faculty, though organizing programs and securing faculty buy-in can present barriers (Healey et al., 2014). As animal sciences progresses toward greater inclusivity and more participatory undergraduate engagement, the quality of undergraduate research programs will play a central role in the functioning of the academic community.

6.4.6 Correlations among LO and CE

Table 5 presents Spearman correlation coefficients among instructors' perceived importance of LO and CE variables. Core experiential learning (CE-1) had a significant positive correlation with analytical, collaborative skills (LO-2); multi-modal communication skills (LO-3); and discipline-specific competencies (LO-4). Community-integrated learning (CE-3) showed a strong positive correlation with practical agribusiness competencies (LO-1). Discipline-specific competencies (LO-4) had significant positive correlations with all CE except community-integrated learning (CE-3), and most strongly correlated with global and research experiences (CE-4) and lecture-based and capstone learning (CE-5). In contrast, all other LO were correlated with only one CE, with LO-2 and LO-3 equally associated with CE-1. These results indicate an overlap between instructor ratings of certain LO and CE, that is, that instructors who rated the CE as important were likely to rate the correlated LO as important as well, and the inverse. Results may further imply that instructors perceive specificity of certain LO to certain CE, with the exception of discipline-specific competencies (LO-4), which instructors perceived as more universally important across CE. Ceiling effects may have influenced results, as well as instructors' familiarity biases. Still, these associations offer a deeper look into the portrait of LO and CE valued by instructors.

6.4.7 Limitations and Future Directions

Our survey and scoping review represent an empirical deep dive into animal sciences teaching and learning topics since the ASAS centennial. Our research has at least six limitations. First, our survey assessed a small convenience sample of instructors across a limited timeframe. Our sample showed a distinct bias toward faculty with teaching appointments at research-focused doctoral universities and may not reflect the entirety of animal sciences faculty involved in teaching. Future work considering a larger, more random (or more purposive) sample of faculty across more diverse institution types may provide more generalizable insight. However, we also encourage research situated within specific subpopulations (e.g.,faculty at junior colleges, administrators) to determine the particular needs and views of each group. Second, we constructed our own survey and relied on instructors to honestly self-report their perceptions. This approach is subject to investigator biases in survey construction and testing effects such as survey fatigue. Qualitative methods such as interviews or portfolio analysis may provide more valid data regarding instructor perceptions. Third, the results from our PCA—a purely mathematical, descriptive technique—are by no means intended as a comprehensive analysis of the structure and dimensionality of LO and CE. Such conclusions would require a larger sample size and accounting for the latent factor structure through factor analytic techniques (Kaplan, 2009). Fourth, our scoping review relied on provisional codes generated empirically through PCA. Although this approach minimized researcher bias in code generation, it does not capture important themes that might have emerged directly from the literature through qualitative analysis. Fifth, our scoping review summarized the volume of research on a large number of topics but did not address research on particular topics in-detail. We anticipate that future review papers will synthesize the research on much-needed topics as the volume of research in these areas increases. Finally, our creation and interpretation of research results is inextricable from our positionality and proximally influenced by our identification as animal scientists and instructors involved in research and teaching. None of our research team believes that any one LO or CE is best, rather, as Bourner (1997) suggests, that the best teaching methods and learning goals depend on the desired outcomes. However, unconscious biases such as familiarity may have influenced our analysis.

6.5 Conclusions

Our research empirically examined animal sciences teaching and learning topics since the ASAS centennial using an instructor survey and a scoping review of the literature. Instructor ratings showed that discipline-specific competencies and core experiential learning remained central to animal sciences' pedagogical identity. However, our results suggest emerging needs for internet-based and international learning opportunities. Our scoping review identified a gap in research assessing transferable skills driven by low quality and quantity of published research. Additionally, our results revealed needs for more research on community-integrated learning, global and research experiences, and internet-based learning. Ultimately, our results reinforce that developing scholarship of teaching and learning specific to our discipline is a requirement for teaching excellence and represents our greatest means for advancing animal sciences teaching to meet emerging challenges in the next century. Moving forward, we recommend that faculty, staff, and administrators work to:

- Use and document use of a greater variety of pedagogies, especially those online, international, integrated with the community, involving undergraduate research, and/or targeting transferable skills
- Make specific transferable skills explicit in curriculum and incorporate rigorous, mixed-methods assessment
- Partner with diverse experts both within and beyond animal sciences to catalyze knowledge-sharing across disciplines, institutions, and experiences
- Develop situated theory and report on pedagogical content knowledge for emerging topic areas such as sustainability, data science, international agriculture, welfare science, and agricultural social science, among others
- Define animal sciences' teaching and learning identity through a greater volume of interpretivist, theory-building work separating classroom, departmental, institutional, and discipline-based characteristics

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6.8 Tables and Figures

Table 6.1. Demographics of the survey participants. N = 90.

Category	N	%
Gender		
Female	36	40
Male	54	60
Citizenship		
US	74	85
Other	13	15
Race/Ethnicity		
White	71	86
Minority	12	14
Undergraduate degree completion		
US	78	89
Other	10	11
Graduate degree completion		
US	84	95
Other	4	5
Family educational history		
First generation to attend college	36	47
One or both parents has a college degree	41	53
Professorial rank		
Assistant professor	32	36
Associate professor	26	29
Full professor	32	36

Table 6.2. Eigenvalues, percentage of variance, and cumulative percentage of variance for the identified principal components on instructors' perception on importance of learning outcomes and types of courses and experiences.

PC[1]	eigenvalue	%var.	cumulative %var.
Importance of learning outcomes			
LO-1	5.20	37.2	37.2
LO-2	1.73	12.4	49.5
LO-3	1.23	8.8	58.3
LO-4	1.12	8.0	66.3
Importance of types of courses and experiences			
CE-1	3.46	24.7	24.7
CE-2	1.96	14.0	38.7
CE-3	1.47	10.5	49.1
CE-4	1.37	9.8	58.9
CE-5	1.08	7.7	66.6

[1]LO-1 = Practical agribusiness competencies, LO-2 = Analytical, collaborative skills, LO-3 = Multi-modal communication skills, LO-4 = Discipline-specific competencies
CE-1 = Core experiential learning, CE-2 = Internet-based learning, CE-3 = Community-integrated learning, CE-4 = Global & research experiences, CE-5 = Lecture-based and capstone learning
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Table 6.3. Principal component loadings and scores for instructors' perception of the importance of learning outcomes (LO).

	PC Loading[1]			
Principal Component	LO[2]-1	LO-2	LO-3	LO-4
LO-1 – Practical agribusiness competencies				
International agricultural systems	**0.86**	0.20	0.02	0.09
State and federal policies related to agriculture	**0.74**	0.20	0.30	0.04
International agri-business marketplace	**0.81**	0.17	0.06	0.14
Languages other than English	**0.74**	0.07	0.19	0.07
Intercultural competence	**0.64**	0.48	-0.12	0.07
LO-2 – Analytical, collaborative skills				
Ability to apply, analyze, and evaluate	0.14	**0.63**	0.53	-0.14
Problem-solving - as an individual	0.00	**0.76**	0.24	0.22
Problem-solving - in team settings	0.22	**0.64**	0.36	-0.08
Decision-making in the face of uncertainty	0.38	**0.59**	-0.11	0.24
Ethical reasoning and action	0.37	**0.71**	0.01	0.11
LO-3 – Multi-modal communication skills				
Oral and written communication	0.20	0.24	**0.75**	0.14
Interpersonal communication	0.04	0.03	**0.82**	0.12
LO-4 – Discipline-specific competencies				
In depth animal science	0.03	0.14	0.19	**0.77**
The scientific method	0.20	0.05	0.01	**0.79**

[1]Rotated factor patterns expressed as principal component loadings
[2]LO = learning outcomes
Items "Gain life-long learners' skills" (0.23), "Demonstrate an ability to remember, understand, and explain" (0.38), and "Leadership development skills" (0.46), "Gain appreciation of global issues in food and agriculture" (0.49), were removed from the analysis due to lower communality values.

Table 6.4. Items and principal component loadings for instructors' perception on importance of types of courses and experiences (CE).

Principal Component	Principal Component Loading				
	CE[1]-1	CE-2	CE-3	CE-4	CE-5
CE-1 – Core experiential learning					
Hands-on laboratories	**0.64**	0.09	-0.19	0.00	0.24
Discussion of pre-assigned readings	**0.48**	0.35	0.30	0.17	-0.26
Computer simulation, modeling	**0.58**	0.41	0.28	-0.12	-0.14
Collaborative work	**0.70**	0.11	0.24	0.17	-0.05
In-country internships	**0.72**	-0.31	0.16	0.15	0.26
CE-2 – Internet-based learning					
Using the internet as a learning tool	0.02	**0.90**	0.05	0.04	0.10
Using the internet as a communication tool	0.10	**0.87**	0.06	0.05	0.11
CE-3 – Community-integrated learning					
Service learning	0.09	0.27	**0.73**	0.02	-0.13
"Real-world", project-based activities	0.17	-0.07	**0.77**	0.17	0.22
CE-4 – Global & research experiences					
International experience (field-trip, study abroad, etc.)	0.18	-0.07	0.42	**0.62**	-0.03
Internships abroad	0.27	0.00	0.19	**0.81**	0.00
Undergraduate research experience	-0.12	0.13	-0.16	**0.81**	0.11
CE-5 – Lecture-based & capstone learning					
Power Point-based lectures	0.14	0.26	-0.28	0.07	**0.69**
Capstone projects	0.05	-0.01	0.40	0.03	**0.74**

[1]CE = types of courses and experiences

Items "Writing-intensive courses" (0.33), and "Business and human resource management" (0.45), were removed from the analysis due to lower communality values.

Table 6.5. Spearman correlations among instructors' perceived importance of learning outcome (LO) and course/experience (CE) variables. N = 90.

Courses/ Experiences[1]	Learning Outcomes[2]			
	LO-1	LO-2	LO-3	LO-4
CE-1	0.07	0.31**	0.31**	0.23*
CE-2	0.04	-0.01	-0.03	0.26*
CE-3	0.37***	0.19	0.01	0.06
CE-4	0.18	-0.07	0.05	0.35***
CE-5	-0.01	0.08	0.04	0.33**

[1]CE-1 = Core experiential learning, CE-2 = Internet-based learning, CE-3 = Community-integrated learning, CE-4 = Global & research experiences, CE-5 = Lecture-based and capstone learning

[2]LO-1 = Practical agribusiness competencies, LO-2 = Analytical, collaborative skills, LO-3 = Multi-modal communication skills, LO-4 = Discipline-specific competencies

*p<0.05, **p<0.01, ***p<0.001

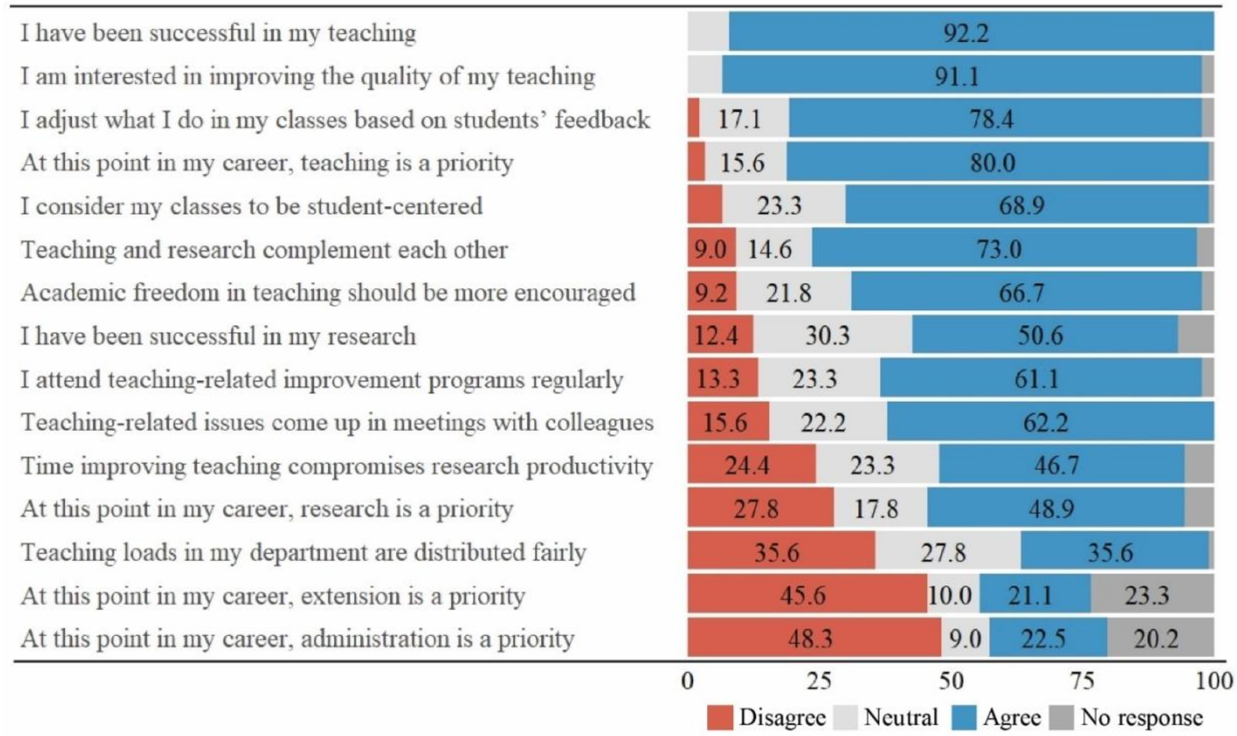

Figure 6.1. Instructor beliefs and perceptions related to their personal teaching practice.[1]

[1]Percentage in each of four categories based on participants' level of agreement on a scale of 1 to 10: 1-4 (disagree), 5-6 (neutral), 7-10 (agree), or N/A (no response). N = 90.

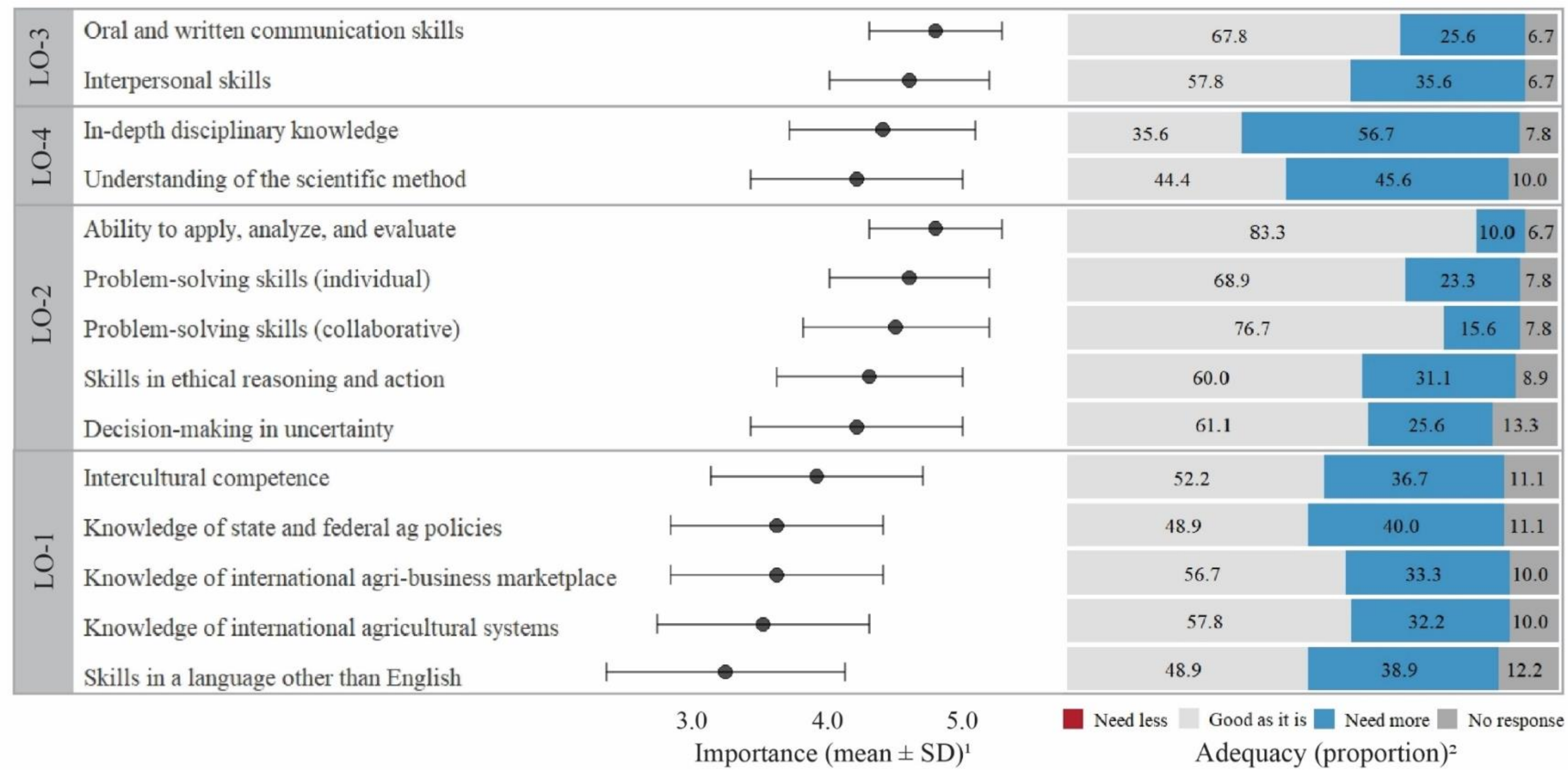

Figure 6.2. Instructor perceptions of the importance of selected learning outcomes (LO) and the adequacy of teaching with regard to LO at their institution.

[1]Mean ± SD of instructor perception of importance on a Likert scale from 1 (not at all) to 5 (a great deal).

[2]Percentage of instructors within each category representing their perception of the adequacy of teaching with regard to each LO at their institution.

[3]LO-1 = Practical agribusiness competencies, LO-2 = Analytical, collaborative skills, LO-3 = Multi-modal communication skills, LO-4 = Discipline-specific competencies

Note: Sorted by mean principal component score, item score.

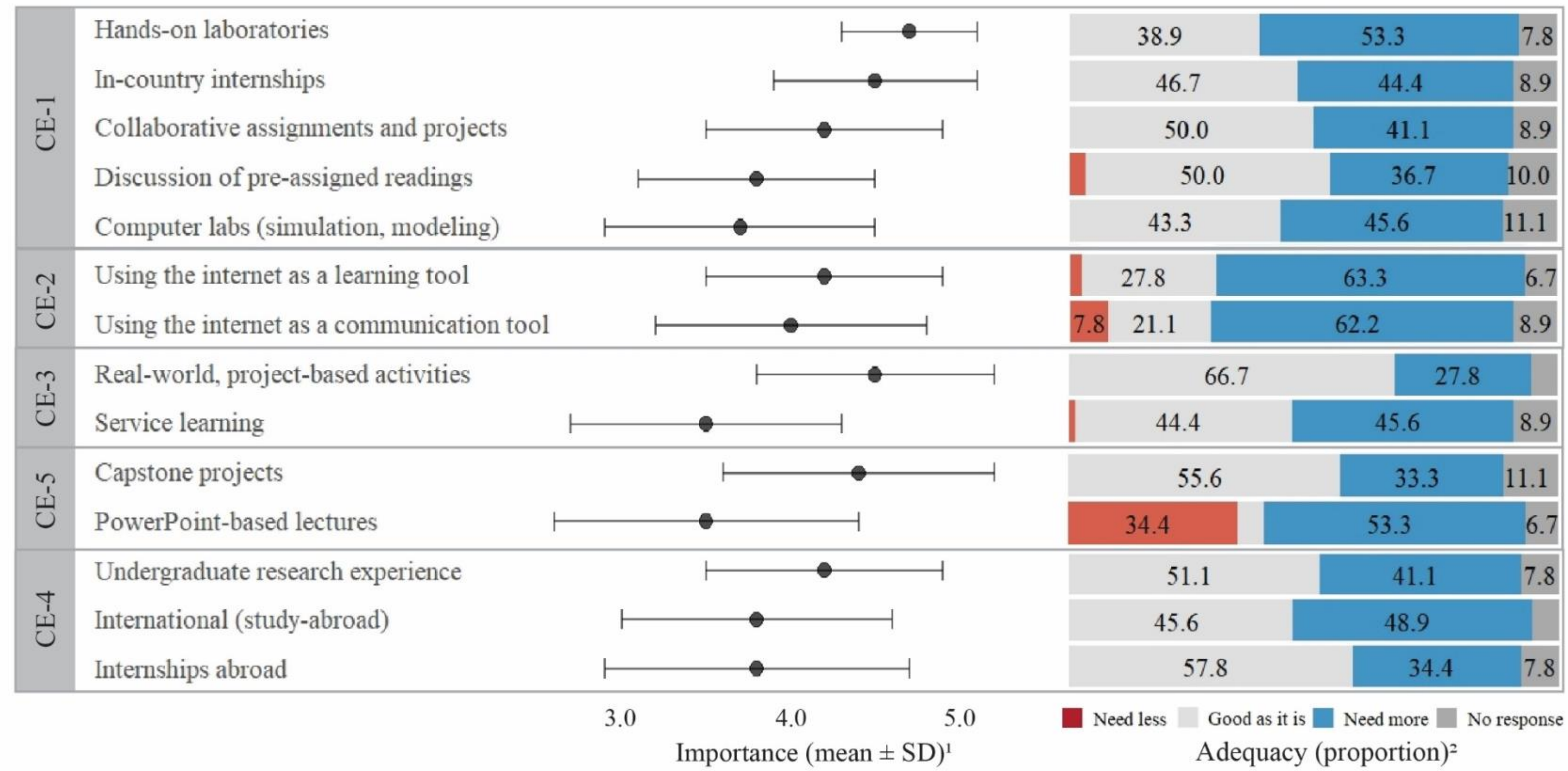

Figure 6.3. Instructor perceptions of the importance of selected courses and experiences (CE) and the adequacy of teaching with regard to CE at their institution.

[1]Mean ± SD of instructor perception of importance on a Likert scale from 1 (not at all) to 5 (a great deal).

[2]Percentage of instructors within each category representing their perception of the adequacy of teaching with regard to each CE at their institution.

[3]CE-1 = Core experiential learning, CE-2 = Internet-based learning, CE-3 = Community-integrated learning, CE-4 = Global & research experiences, CE-5 = Lecture-based and capstone learning

Note: Sorted by mean principal component score, item score.

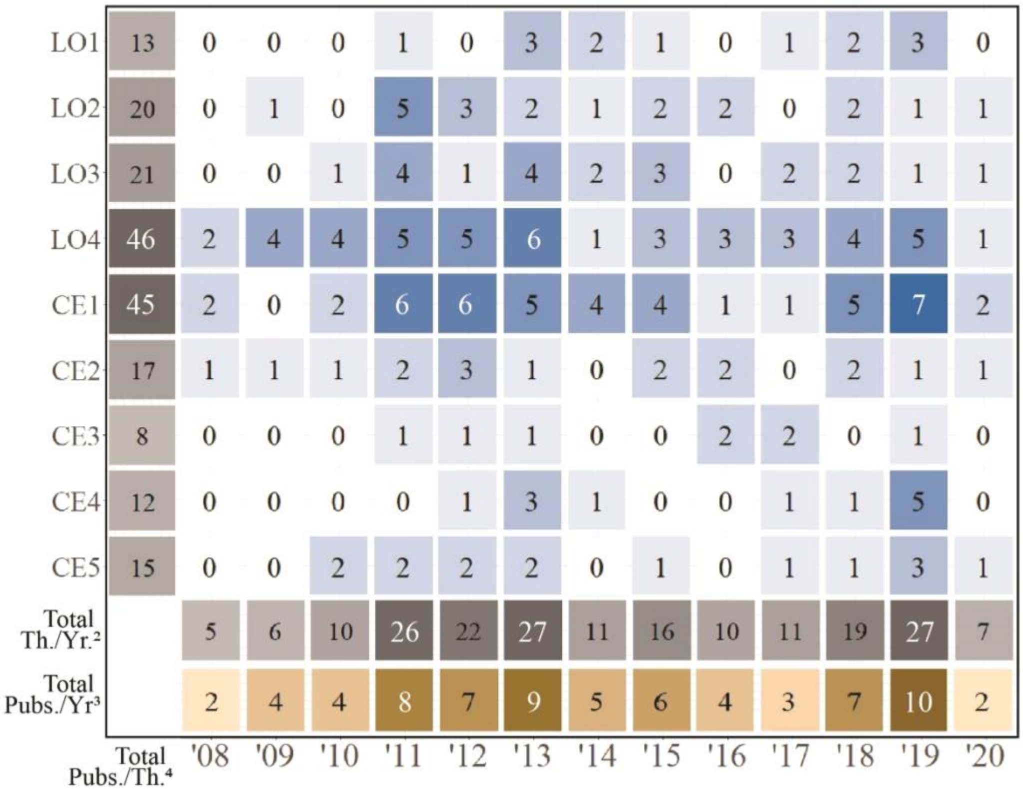

Figure 6.4. Frequency of teaching & learning publications coded within provisional themes by year. N = 71.[1]

[1]LO-1 = Practical agribusiness competencies, LO-2 = Analytical, collaborative skills, LO-3 = Multi-modal communication skills, LO-4 = Discipline-specific competencies

CE-1 = Core experiential learning, CE-2 = Internet-based learning, CE-3 = Community-integrated learning, CE-4 = Global & research experiences, CE-5 = Lecture-based and capstone learning

Note: Represents the range from 01/01/2008 to 05/01/2020

[2]sum of codes per year

[3]sum of publications per year

6.9 Appendix: Scoping Review & Qualitative Methods

Scoping Review Procedures

To integrate recent scholarly literature into our analysis, two members of our research team (M. E. and M.W) searched and screened the peer-reviewed literature targeting full-length articles on undergraduate teaching and learning in animal sciences published between 01/01/2008 and 05/01/2020. Our initial search of the CABI database netted 619 publications. To recover recent papers not yet indexed, we searched within websites for the NACTA Journal and the Journal of Animal sciences, discovering 24 additional papers. Then, we searched for grey literature by examining articles citing the related ASAS Centennial Papers by Buchanan (2008) and McNamara (2009). This yielded 8 dissertations and 1 additional full-length publication. Then, we began to filter the 651 total populations by examining title and metadata. We excluded publications that focused on populations other than undergraduate students (e.g. K-12, industry stakeholders, faculty), those offered outside of animal sciences departments (e.g. veterinary medical education), and those where research occurred outside the U. S. All study designs were eligible, however, we excluded editorial papers and those with an exclusively historical focus. Following title- and metadata-based screening, 90 papers remained. We next closely read all abstracts, eliminating an additional 19 papers based on the same criteria. The 71 remaining full-text articles served as the database for our scoping review. Selected publications represented a range of descriptive, associational, case study, quasi-experimental, and experimental research designs and employed qualitative, quantitative, and mixed methods. Notably, research design and methodology appeared biased toward positivist, nomothetic traditions, with no publications in our sample utilizing action research, idiographic, or ethnographic approaches and few explicitly building theory.

Coding Procedures

Next, we applied the LO and CE categories discovered through our PCA as a priori themes for provisional coding (Saldaña, 2009). We combed through the full-text articles and assigned LO and CE codes to each paper based on the explicitly stated context, participants, intervention (if present), and measured variables. After initial coding, researchers discussed closely re-read and discussed contentious papers to determine final codes. We discovered a median of 3 codes per publication (min. = 1, max. = 6).

Qualitative Methods and Trustworthiness

To ensure trustworthiness, our review and qualitative analysis utilized well-established methods to examine multiple, overlapping sources of data—integrating survey data with the peer-reviewed research published recently (Shenton, 2004). Our research team, as animal scientists involved in scholarship of teaching and learning, was familiar with the topic, the literature, and to a more limited degree, the population of animal sciences instructors in the US. This expertise, combined with reflective commentary on our own beliefs and assumptions, helped us enhance the credibility and confirmability of our research. We used empirically-generated codes, frequent debriefing, and negative case analysis to maintain integrity throughout qualitative procedures. Our detailed methodological descriptions are intended to provide an audit trail allowing readers to scrutinize both the trustworthiness of our findings and their applicability to particular situations (Carcary, 2009).

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CHAPTER 7. BRIEF WRITTEN REFLECTIONS IMPROVE INTEREST OF INTRODUCTORY ANIMAL SCIENCE STUDENTS

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7.1 Abstract

In addition to stimulating interest through experiential means, educators can support interest development through structured reflection. Our randomized controlled intervention study assessed the effectiveness of 10-minute written utility value reflections designed to enhance the interest of introductory animal science students. During the spring 2019 semester, we randomly assigned participating students into two blocks, utility value reflection (n = 39) and control (n = 34), at the beginning of the course. On 6 weeks during the 16-week semester, students completed corresponding tasks: either written reflections on the personal value of course laboratory material or a control picture summarization task. Results showed that the utility value reflection intervention tended to improve situational interest and was most effective for students with low pre-test individual interest. Neither the intervention nor interest variables predicted course performance. In utility value reflection responses, we cataloged themes aligned with a range of task value components beyond utility value. Our results reinforce previous work indicating that utility value reflections support low-individual-interest students in developing academic motivation.

7.2 Introduction

"Interest is obtained not by thinking about it and consciously aiming at it, *but by considering and aiming at the conditions* that lie back of it, and compel it" (Dewey, 1913, pp. 95).

Most college educators can speak at length on the benefits of having interested students (Ulriksen, 2009; Wong & Chiu, 2018). Indeed, research has shown that interested students tend to be more attentive, persistent, and effortful in the classroom (Hidi & Renninger, 2006), and that interest significantly correlates with academic performance and deep learning (Alexander, 1997; Schiefele et al., 1992). Still, in "hard applied" disciplines such as animal science, many educators struggle to leverage interest effectively (Becher, 1987, p. 289; Hidi & Harackiewicz, 2000). Among these teachers, there is widespread belief that interest is something permanent that students either have or do not have (Hidi & Renninger, 2006). Recently, however, experimental studies on interest (hereafter termed *intervention* studies) have proliferated—offering compelling evidence that educators in hard science disciplines can impact interest development through even minor actions in the classroom, particularly when initial interest is low (Harackiewicz et al., 2016; Rosenzweig & Wigfield, 2016).

Colloquially, interest refers to feelings of curiosity, engagement, and excitement. In psychology, theorists have described interest as a motivational process that emerges from dynamic person-environment interactions and has both affective and evaluative components (Izard, 2007; Schiefele, 2009). According to the Four-Phase model of interest development, interest occurs in several distinct forms. The most immediate, contextualized form of interest is *situational interest*, which occurs when features of the environment trigger heightened attention or affect towards an object or topic. Over time, interest can develop into a more stable, trait-like disposition referred to as *individual interest.* This represents interest's crystallization as an aspect of identity and personality—the predisposition to re-engage with a particular material over time (Hidi & Renninger, 2006). The two forms of interest are distinct, but often coincide (Hidi & Renninger, 2006).

The unique features of interest make it possible to employ a variety of interest-enhancing interventions in educational settings. For example, in past efforts, we attempted to improve animal science students' interest by altering experiential characteristics of educational activities (Erickson et al., 2019). Like others, we documented that active learning modalities such as hands-on or problem-based learning produced higher levels of situational interest for our students (Erickson, Marks, et al., 2020; Schraw & Lehman, 2001). In theory, these richer, more realistic, more personalized learning experiences stimulated greater interest in our students by interacting in broader, deeper ways with learners' ongoing affective, cognitive, sensorimotor, and psychosocial processes (Izard, 2007; Jarvis, 2004; Marton & Säljö, 1976).

In addition to shaping learning experiences, educators also affect interest development by guiding learners' processes of reflection. As learners reflect, they consolidate experiences into internalized value and meanings (Kolb, 1984). In the current study, we build on appraisal, functionalist, and dynamic systems theories of emotion, which suggest that interest emerges as learners interpret their experiences within complex personal frameworks (e.g. appraisals, values, goals, instrumental actions; Lewis & Granic, 2000; Witherington & Crichton, 2007) amid social forces (Markus & Kitayama, 1994). We assume that reflection, as a metacognitive meaning- and sense-making process, influences interest development by altering individuals' subjective task value (Eccles & Wigfield, 2002; Sandars, 2009).

7.2.1 Expectancy-Value Theory

Interventions that manipulate interest by enhancing subjective task value are rooted in Expectancy-Value Theory (EVT) of achievement motivation (Eccles & Wigfield, 2002). EVT proposes that an individual's motivation is determined by the expectancies (beliefs about outcomes of particular tasks) and subjective values (usefulness, enjoyment, importance) they ascribe to particular tasks. A great deal of research describes the importance of expectancies in motivation (see Pintrich & Schunk, 1996 for a review). Task value, on the other hand, has only recently captured the attention of educational researchers. Due to its considerable conceptual overlap with interest, task value research has grown substantially alongside developments in interest theory and nation-wide efforts toward student-centered, interest-driven learning. Conceptually, task value comprises four components, each of which contributes to the experience of situational interest and the development of individual interest: 1) attainment value, the personal significance of doing well, 2) intrinsic value, the amount of enjoyment the individual derives from the task, 3) utility value, how the task relates to future goals, and 4) costs, what the individual has to give up to accomplish the task (Eccles & Wigfield, 2002). The former three components interact to contribute positively to interest development, while perceived costs can detract (Flake et al., 2015).

7.2.2 Improving interest through reflection-based interventions

Reflection-based interest interventions typically aim to communicate the value of course material to participants—encouraging them to internalize it as meaningful (Rosenzweig & Wigfield, 2016). Researchers have attempted a variety of interventions, differing on several levels.

First, communicating value can occur through direct testimony (i.e., a teacher or older student shares why the material is relevant) or through prompts that encourage students to self-generate task value messages (Durik, Hulleman, et al., 2015). Directly communicating value appears to increase interest for certain students but can undermine interest for low-performing or low-expectancy students (Durik, Shechter, et al., 2015). Conversely, student-centered messages appear to have consistently positive or achievement-gap-closing effects (Harackiewicz et al., 2016).

Second, interest interventions differ in their targeted motivational outcomes. While some researchers fix attention on specific components of task value (e.g. utility value; Brown et al., 2015; Hulleman et al., 2010), others consider a combination of utility, attainment and intrinsic value (e.g. Acee & Weinstein, 2010). Indeed, although attainment, utility, and intrinsic value attributes of task value are conceptually distinct, they are often positively correlated (Eccles & Wigfield, 1995). Previous attempts to manipulate a single component (utility value) have ultimately affected other aspects of task value and expectancies (Priniski et al., 2018; Hulleman et al., 2017).

Finally, interventions differ in intensity and duration. Researchers have enhanced interest with interventions as short and simple as two writing tasks for students (Hulleman et al., 2010) or as involved as a two-year, multi-platform, two-generation intervention (Harackiewicz et al., 2012). The optimal dosage and intensity depend on desired outcomes and student and classroom characteristics (Canning et al., 2018). However, researchers have recently focused efforts on (1) testing and refining broadly-applicable interventions requiring low input from instructors and (2) developing understanding of intervention functioning specific to certain instructional contexts.

7.3 Purpose And Objectives

Our randomized controlled intervention study sought to empirically test the effects of a brief written utility value reflection intervention, conducted at four timepoints throughout the semester, on the situational interest of introductory animal science students. The following objectives guided our research:

1. Qualitatively explore task value themes produced by the utility value reflection group.
2. Test the effectiveness of a reflection-based utility value intervention throughout the semester for students with varying levels of pre-test individual interest.
3. Evaluate the relationships among treatment condition, pre-test and post-test individual interest, average situational interest during the semester, and course performance.

7.4 Method

7.4.1 Context and Participants

We conducted our experiment during the spring 2019 semester of an Introduction to Animal Agriculture course. This 16-week course is a medium-enrollment (approximately 90-110 students) introductory course typically consisting primarily of first-year and pre-veterinary students with relatively little experience in animal agriculture (Erickson et al., 2019). The course comprises twice-weekly 50-minute lectures and a weekly 110-minute laboratory session. All experimental procedures took place during course laboratories.

The lead instructor for the course taught course lectures using a Powerpoint-based interactive lecture approach (Bernstein, 2018). One undergraduate teaching assistant (TA) assisted the lead instructor in lecture instruction and administrative tasks. A graduate laboratory coordinator and a total of 11 undergraduate TAs (2-3 per laboratory section) facilitated the course's five laboratory sessions. The laboratory coordinator and laboratory TAs carried out experimental procedures for this study. The Institutional Review Board approved all study procedures.

7.4.2 Study Design

Table 1 summarizes the schedule of experimental procedures, and response rates across experimental periods are shown in Table 2. The experimental sample consisted of 73 students who completed both the pre- and post-tests. Of 100 total students in the course at the beginning of the semester, we enrolled a subset (n = 91) in our study via a pre-survey. Eight students missed the pre-survey or opted out of participation, and one student dropped the course. The responses of 18 additional students who did not complete the post-survey were excluded.

We assigned each student to a unique treatment group for the duration of the study: either the control picture summarization group (CTRL) or the utility value reflection group (UVR). To assign treatments, we used block-randomization to ensure equal sample sizes and reduce the potential for error in administering the intervention and control conditions (Suresh, 2011). Prior to the first laboratory sessions, we randomized students in each laboratory section into four blocks, consisting of 4-6 students each, for a total of 20 blocks. For each laboratory section, we randomly selected two blocks and assigned them to the intervention condition. Students in the remaining two blocks served as that laboratory section's control group. We repeated this procedure for each of the course's five laboratory sections. Prior to experimental analysis, we used Chi-squared and Welch's two-sample t-tests to verify successful randomization, i.e., that no significant differences existed between control and intervention groups for baseline covariates (Table 3). Pre-test individual interest and frequencies of females and underrepresented minorities did not differ between CTRL and UVR groups. However, a significant Chi-squared test indicated that first-generation college attendance was non-independent from the treatment condition.

Students completed a pre-survey assessing demographics and baseline situational and individual interest. Then, they completed the intervention or control activities on six non-consecutive weeks during the semester, during which time they intermittently completed surveys on their situational interest and to validate correct treatment administration. Finally, students completed a post-test on situational and individual interest at the end of the semester. Students received extra credit for participation in surveys and laboratory participation points for completing written activities.

7.4.3 Utility Value Reflection Intervention

For both UVR and CTRL treatment groups, we used written prompts to guide students in brief, 10-minute writing activities (Table 4). The UVR group prompts were based on the utility-value prompts developed by Hulleman et al. (2010) and were intended to stimulate reflection on the material's utility value. Conversely, the CTRL group completed a picture summarization task intended to bring the material to mind for a rote purpose without prompting reflective meaning-making.

Although the UVR prompts were intended to target utility value, two manipulation checks indicated that additional components of task value were reflected in students' experiences with the intervention. First, one researcher read through student responses, noting a substantial focus on the intrinsic value of material. Second, we quantitatively assessed utility value following an initial test of the intervention, using a 3-item scale developed by Hulleman et al. (2010). We were unable to differentiate between CTRL and UVR groups on the basis of utility value ratings, and the scale was not internally consistent with our group. The lack of specificity to utility value may be due to its strong correlations with other aspects of task value and is consistent with other utility-value intervention studies (Priniski et al., 2019).

7.4.4 Instrumentation

To measure situational and individual interest, we selected questionnaires conceptually aligned with our operationalization of interest development as an active, relational process organizable into phases and influenced both by experiences and reflective appraisals: Linnenbrink-Garcia and colleagues' (2010) Situational Interest Questionnaire (SIQ) and Individual Interest Questionnaire (IIQ). We adapted wording to make items specific to our context. For situational interest, items reflect the Introduction to Animal Agriculture class (e.g. "My ANSC 102 class is exciting"). For individual interest, items refer to animal sciences as a discipline (e.g. "Animal sciences is practical for me to know").

We assessed reliability during the initial experimental period. Our modified individual and situational interest questionnaires demonstrated excellent reliability, with standardized Cronbach's α coefficients of 0.96 and 0.97, respectively. To validate that students had completed the treatment intended (i.e., that no student had switched groups and/or received the wrong activity) we had students input an identifier from their written assignment in their online survey at three timepoints (weeks 6, 7, and 12). Results verified that 100.0% of students received the correct treatment during all three intervention days.

Course instructors provided grades on a percentage basis at the end of the semester. Grading was criterion-based and consistent across laboratory sections. We assessed course performance using final course grades (*M* = 86.7 *SD* = 6.7) and students' average scores on weekly laboratory quizzes (*M* = 7.9, *SD* = 1.0). We used scores on the first exam (*M* = 75.2 , SD = 10.7) and the first five laboratory quizzes (*M* = 8.3, *SD* = 0.8) to control for early-semester performance. Exam and course grades are shown on a percentage basis while laboratory quiz scores are presented out of 10 possible points.

7.4.5 Experimental Procedures

To collect data for weeks 6, 7, and 12—the validation timepoints—students began the laboratory by completing normal class activities (held constant across groups). Then, we instructed all students that they would be completing a writing activity before proceeding. We divided students (n = 18 to 25 per laboratory section) and seated subgroups in four separate areas of a large laboratory space. Students in two subgroups received the control activity (CTRL; picture summarization task) and students in the remaining two subgroups received the intervention (UVR; utility value reflection). We instructed students that they would have 10 minutes to complete the activity. The course laboratory coordinator and two undergraduate TAs monitored students during the task and answered clarification questions. The course instructor, the undergraduate TAs, and the students in the course were blind to experimental treatments, which the laboratory coordinator administered for all course sections. After 10 minutes, we instructed students to cease working on the activity and place them face down on the table. Then, they scanned a QR code and completed a questionnaire on their laptop or mobile device, using as much time as needed. On weeks 5, 9, and 13, students completed the UVR or CTRL activities during bus-rides back from facility tours. Undergraduate TAs supervised students during the process. No questionnaires were administered at these timepoints. Topics varied from week to week (wk. 6 = goat health, wk. 7 = equine nutrition, wk. 12 = mastitis management, wk. 13 = poultry production).

7.4.6 Statistical Analysis

We conducted all statistical analyses in R (R Core Team, 2019) declared significance at $p<0.05$ and tendencies at $p<0.10$. To examine situational interest data across the four time points (Objective 1), we used restricted maximum likelihood estimation to build linear mixed models (LMM) using the lme4 package (Bates et al., 2015) and assuming that data were missing at random (Twisk et al., 2013). We centered and scaled all continuous independent variables relative to sample means and applied a Box-Cox transformation to situational interest to correct for non-normality (Box & Cox, 1964; West, Welch, & Galecki, 2014). Model results are presented as situational-interest-squared, while estimated marginal means are backtransformed to the original scale.

We tested several random effects specifications to account for hierarchical nesting. We retained a random intercept for student, but not student section or laboratory group, based on likelihood ratio-based nested model comparisons and Bayesian Information Criterion (BIC). Fixed effects included the pre-test individual interest, a dummy-coded intervention contrast (1 = UVR, 0 = CTRL), score on the first exam, score on first five laboratory quizzes, experimental period, and the interactions of the intervention with pre-test individual interest and experimental period. We retained non-significant fixed effects due to their relevance to our objectives and theoretical importance as predictors. We verified normality of residuals graphically and computed variance inflation factors to check for multicollinearity.

To explore the interaction between the intervention and pre-test individual interest, we trichotomized the pre-test individual interest variable (thresholds = 6.0, 6.6). Gelman and Park (2009) suggested that splitting into three rather than two n-tiles preserved more power for post-hoc comparisons. We computed estimated marginal means for situational interest conditioned on high, medium, and low pre-test individual interest for each treatment using the emmeans package (Lenth, 2019). Because we hypothesized positive associations between the intervention and situational interest, we used one-sided significance tests for post-hoc pairwise Tukey's tests (Figure 1).

To examine Objective 2, the relationships among treatment group, pre-test individual interest, post-test individual interest, average situational interest during the four experimental periods, average laboratory quiz score, and course grade, we computed Kendall and point-biserial correlations using the "correlation" package (Table 5; Makowski et al., 2019). We used an average of situational interest across available timepoints for students missing observations at periods 1, 2, and 3.

7.4.7 Qualitative Analysis

Our qualitative analysis involved a two-part examination of student responses to treatment prompts: 1) examining themes in utility-value responses (Objective 3) and checking theoretical validity, 2) checking the validity of the control condition. To prevent confounding, we performed all qualitative analyses after the conclusion of quantitative experimentation.

To conduct an additional manipulation check and explore for common themes, we analyzed intervention group responses to all six utility value prompts using template analysis (Brooks et al., 2015). Template analysis permitted us to define a priori categories based on Eccles and Wigfield's (1995) conceptualization of task value. We applied standard template analysis procedures to our data, consisting of several steps. First, one of the researchers familiarized themselves with the data by reading and re-reading responses and noting initial codes. Then, they developed a preliminary list of codes and began searching for meaningful clusters, mapping the codes hierarchically into themes. Then, they grouped themes into categories based on the a priori theoretical framing and selected representative quotes. Finally, they reviewed themes against the extracted codes and the original dataset, checking for consistency (Braun & Clarke, 2006).

To verify that the control picture summarization task (CTRL) functioned as intended and that student responses were distinct from responses to the utility value prompts, we used a deductive, rapid analysis approach using the task value codes as a pre-defined contrast (Taylor et al., 2018). A researcher first spent approximately one hour looking through control task responses and noting any key issues (i.e. responses appearing to use task value language). Then, the researcher used a pre-prepared summary template to sort out acceptable and questionable responses to picture summarization prompts, noting the respective fractions in each category.

Our research employed several measures to ensure qualitative trustworthiness. To ensure credibility, we grounded our research in well-established theories, utilized widely accepted methods, and examined our results in light of previous findings (Shenton, 2004). To establish dependability and transferability, we provide detailed methodological description including important pieces of our reflective commentary throughout the research process. Additional strategies for trustworthiness included early familiarity with the culture of participants and tactics to ensure their honesty in surveys. The analysis of our study employed peer scrutiny and negative case analysis to enhance trustworthiness of conclusions (Silverman, 2001).

7.5 Results

7.5.1 Demographics

Table 3 summarizes demographic information of CTRL and UVR groups, showing no significant differences between treatment groups for each of the observed baseline covariates. On average, our participants reported high individual interest in the subject at both the start and end of the semester. Although post-test individual interest was numerically lesser (M = 6.12, SD = 1.04) than pre-test individual interest (M = 6.21, SD = 0.74), a paired t-test indicated no significant differences between mean individual interest in the pre- and post-tests ($t(72) = 0.75$, $p = 0.46$). The majority of our participants were female, white, and were not first-generation college attendees.

7.5.2 Themes in Articulated Task Value

Table 5 summarizes all student responses to six utility value prompts throughout the semester. Although the reflection prompts were based on utility value, we noted a significant focus on intrinsic and attainment value when examining codes using these a priori themes. Students appeared to derive diverse meanings from their experiences. Only a small fraction of responses (<5%) contained statements communicating a lack of perceived value. In some cases, students indicated that they failed to see a connection between the material and their career plans.

Our introductory animal agriculture course covers a range of topics across species and production systems, so it is plausible that some labs may be more difficult for certain students to connect with. In other cases, students mentioned perceived costs—another important component of task value (e.g. "I have so much respect for the amount of attention and care…I am just realizing [the] production side isn't for me"). In most cases, responses containing negative task value phrases also contained positive messages, indicating that the student had successfully made some connections with material. Therefore, the intervention appears to have functioned to create utility-value-enhancing messages as intended, in addition to creating messages related to other task value components. The control picture summarization prompt also appeared functional in our sample. During rapid analysis, less than 10% of written responses surfaced as questionable (i.e., possibly overlapping with task value responses). These results demonstrate successful implementation of both control and utility value conditions.

7.5.3 Situational interest across the semester

Table 6 presents a LMM describing situational interest across the semester. Across experimental timepoints, situational interest was significantly, positively predicted by pre-test individual interest. Course performance prior to experimentation (average score on first five lab quizzes, first exam score) was unrelated to situational interest. Situational interest did not differ significantly based on experimental periods relative to the reference period, period 1. The utility value reflection tended to improve situational interest. No treatment-by-period interactions significantly predicted situational interest. However, a treatment-by-pre-individual-interest interaction tended toward significant. The marginal coefficient of determination indicated that the fixed effects explained 15% of the variation in situational interest. The intra-class correlation coefficient showed that within-student variation accounted for 65% of total variation, showing consistency within individuals over time.

Figure 1 illustrates estimated marginal mean situational interest in the control and intervention groups throughout the semester expressed on original scale, conditioned on low and high pre-test individual interest. We observed no significant differences between CTRL and UVR groups for the four experimental timepoints in the high pre-test individual interest group or the medium pre-test interest group (p = .43 to .65). In contrast, pairwise comparisons of UVR and CTRL within the low-pretest individual interest group showed a significant positive effect of UVR across all four experimental periods.

7.5.4 Relationships among UVR intervention, interest variables, and course performance

Table 7 shows correlations among measured variables. We discovered no statistically significant pairwise associations between average situational interest during the semester and course performance variables. However, all course performance variables were positively correlated. Pre-test and post-test individual interest showed a strong positive correlation. Average situational interest during the semester had a strong positive relationship with post-test individual interest, but not pre-test individual interest. The intervention contrast was unrelated to course performance and interest variables.

7.6 Discussion

Our randomized controlled study evaluated the effects of a brief, reflection-based utility value intervention on the situational interest and course performance of students in an introductory animal agriculture course laboratory. Our quantitative results showed promise that utility value interventions can produce deep reflection and may enhance situational interest. Our qualitative analysis illuminated a multitude of task-valuing dimensions along which students connected learned material to their lives in response to utility value prompts. In sum, our research confirmed that a self-generated utility value intervention can improve situational interest in introductory animal sciences students. However, it raised additional questions on intervention design and logistics to maximize effectiveness given student and classroom characteristics.

Our analysis of responses to utility value prompts revealed diverse interpretations of the purpose and significance of course material, illustrating the value of allowing students to self-generate task value messages through reflection. Consistent with Harackiewicz et al. (2016), we discovered plentiful references to self, family, friends, and social processes. We were also able to draw gross distinctions between control and utility value responses qualitatively, although we did not conduct in-depth coding or linguistic analysis. Past research has documented significant differences between responses to control and utility value prompts in a number of regards. Harackiewicz et al. (2016) noted greater use of language suggesting cognitive engagement and insight in utility value responses relative to the control task of summarization. Beigman Klebanov et al. (2018) replicated and extended these findings using natural language processing, demonstrating that utility-value prompted writing further produced greater use of argumentative and narrative language. Overall, utility value interventions in our study and in others seem to enhance engagement in reflective meaning-making processes (Johnson & Sinatra, 2013). However, more research is needed to understand the empirical distinctions between utility value and other task value components and reveal the specific values, goals, and needs that motivate particular students and student groups (Harackiewicz et al., 2015; Priniski et al., 2018).

Past research has shown that introductory animal sciences students have high individual interest that remains relatively stable during the semester, and moderate to high situational interest levels that vary with educational experiences (Erickson et al., 2019; Erickson, Wattiaux, et al., 2020). The present study corroborated these findings: individual interest was high at the start and end of the semester and unaffected by the intervention, and situational interest was high throughout the semester but tended to be greater for the UVR group compared with CTRL students. The Four-Phase Model of interest development predicts that greater situational interest could eventually lead to changes in individual interest with repeated or prolonged exposure (Hidi & Renninger, 2006). However, past studies have shown that the timescale for such changes may be longer than a single semester, especially for students starting with high interest (Fryer & Ainley, 2019).

In addition to affecting individual interest development, the high level of interest in our sample may also have dampened the overall effect of the utility value intervention on situational interest. Indeed, our intervention improved situational interest of students with low pre-test individual interest, but it did not alter the situational interest of students with medium or high pre-test individual interest. Other authors have documented similar effects. For example, Hulleman et al. (2010) recorded little to no effects of a student-centered utility-value intervention on students with high positive expectancies, a phenomenon often coinciding with high existing individual interest. Our sample also had few first-generation or underrepresented minority students. Harackiewicz et al. (2015) reports that student-centered utility value interventions tend to be less beneficial to historically privileged college students relative to their disproportionate benefits for students from historically underrepresented groups. Our analysis showed situational interest was not dependent on gender, first-generation status, underrepresented minority status, or early course grades. However, our sample lacked the diversity and size to examine the interactions between the intervention and certain demographic characteristics. Future iterations matching intervention design with student characteristics may improve intervention effectiveness (Priniski et al., 2018).

In contrast with past research describing utility value interventions with respect to performance gaps (Harackiewicz, 2015; Hulleman et al., 2017), our study showed that a utility value intervention closed a gap in situational interest for students with low pre-test individual interest. Although we noted significant positive correlations among all course performance metrics, we found no significant effects of situational interest, individual interest, or the intervention on course grades. These results are both contradicted and supported in previous work. Prior research has firmly established that interest is related to effort, persistence, and the use of metacognitive strategies (Harackiewicz et al., 2016; McWhaw & Abrami, 2001). When manifest (sometimes operationalized as "achievement-related behaviors"), these attributes appear to mediate interest's positive relationship with performance (Chouinard et al., 2007; Rotgans & Schmidt, 2011). However, the predictive value of interest in determining performance is largely dependent on course objectives and grading structure, which can vary greatly in the types of behaviors rewarded (Pintrich & Schrauben, 1992; Schiefele et al., 1992). In theory, interest strongly predicts performance in courses structured to reward deep learning but may not be associated with performance in courses where assessment emphasizes surface-level learning (Harackiewicz et al., 2000). Interventions that successfully enhance interest can therefore have either positive effects or no effects on performance depending on the course (Durik & Harackiewicz, 2007; Hulleman et al., 2010).

Factors related to intervention timing and dosage may also have affected the results we observed. For example, Canning et al. (2018) reported no differences between three doses and a single dose of utility value essay with respect to course performance and continuation to a second course on the topic. The authors also reported timing effects that interacted with student characteristics, suggesting that intervening at the beginning improved course performance of low-performing students, and intervening near the end of the semester improved continuation of high-performing students. We timed interventions during the middle of the semester (weeks 5 through 13), which may have been sub-optimal. Further, unlike Canning et al. (2018), we did not quantify the depth of utility value reflections throughout the semester or offer feedback to students enabling them to improve their skills at utility value reflection. Future experimental and quasi-experimental studies assessing factors related to timing, student pre-course interest level, and articulated task value may clarify optimal conditions for implementation.

Our choice of context—to implement treatments during laboratory sessions rather than course lectures—may also have affected intervention effectiveness in our experiment. Compared with content-focused course lectures, course laboratories offered more diverse constructs, images, and sensations as material for reflection (Jarvis, 2004; Marton & Säljö, 1976). Some students, however, may have found this distracting. Additionally, students completed laboratory activities and experimental reflections in the grouped seating arrangement typical of course labs. Yet, we asked students in the intervention group to introspect deeply on the personal meaning of material. Some students may have found that the grouped setting and other perceptual stimuli detracted from their ability to deeply reflect (Bermúdez, 2017). However, this was an important aspect of our experimental design because it allowed us to constrain the reflection environment and timing for control and intervention groups as constant across students. In the future, educators and researchers might consider relaxing the experimental conditions surrounding reflective activities to allow more natural, autonomous reflection. Preliminary empirical evidence suggests that value interventions incorporating more choice may more successfully enhance task value and subsequent course performance (Priniski et al., 2019; Rosenzweig et al., 2019).

Laboratory topics are another course context factor that may have influenced our results (wk. 6 = goat health, wk. 7 = equine nutrition, wk. 12 = mastitis management, wk. 13 = poultry production). Reiling and colleagues (2003) note substantial variation in introductory animal science students' primary species and topics of interest, suggesting that students with prior agricultural background are more likely to appreciate animal management topics. Conversely, Lyvers-Peffer (2011) showed that animal science students perceived unfamiliar topics to be particularly valuable and interesting. Our qualitative data produced evidence corroborating both assertions. These results are also consistent with interest literature, which suggests that both prior knowledge and a perceived lack of knowledge act as antecedents of situational interest (Berlyne & Parham, 1968; Rotgans & Schmidt, 2014). We suggest that unexplained variance, particularly during weeks 7 and 12, may be attributable to students' mixed reactions to unfamiliar topics. We did not measure students' familiarity or interest on lab-specific topics prior to each laboratory. However, future research may elucidate how these factors mediate the experience and interpretation of interest in animal sciences laboratories. Such research may assume particular importance as universities struggle to generate interest in food-animal academic study and careers, topics increasingly unfamiliar to the average student (Posey et al., 2012).

7.7 Limitations

Our results are qualified by at least six important limitations. First, our experiment assessed a single iteration of a course using a moderately-sized convenience sample of students that lacked diversity in some dimensions. Although this narrow focus allowed us to perform a tightly-controlled test and offer an in-depth description of the conditions surrounding experimentation, our results are not generalizable to other courses or other student populations (Borg & Gall, 1989). Following Shenton (2004), we leave decisions on transferability to the readers of our study, who have deeper knowledge of the areas outside our classroom to which these results may apply. Second, our sample included only those students from whom we had sufficient data. Students who declined to participate, attended the course infrequently, or dropped out of the course are not reflected in results. Third, we documented non-independence between the treatment condition and first-generation college attendance. Given that first-generation college attendance was unrelated to situational interest in our LMM, it is unlikely that imbalance between UVR and CTRL groups significantly affected estimates of treatment effects. Fourth, we did not investigate the longitudinal effects of the intervention, which research suggests may persist or amplify for years following an intervention (Rozek et al., 2017). Colleges of agriculture could consider using routine course assessments to track motivational variables throughout undergraduate degree programs to determine longitudinal effects. Fifth, we assessed only a single aspect of motivation (situational and individual interest), while research suggests that measuring a profile of motivational variables is a finer-grained analysis (e.g. Dietrich et al., 2019; Rosenzweig et al., 2020). Finally, we urge caution in interpreting the magnitude of the intervention's positive effects based on our results. Although our study had sufficient statistical power to confirm our directional hypothesis, it did not afford much precision in estimating the magnitude of effects (Gelman & Carlin, 2014). In addition to meta-analyses, studies with larger samples or cross-over designs may generate more precise information regarding the magnitude of intervention effects.

7.8 Conclusions

Our results offer preliminary evidence that brief, written utility value activities can prompt reflection on multiple aspects of task value and improve interest in introductory animal sciences students. Our findings replicated previous research on STEM utility value interventions and extended it to the context of animal science. Although animal science students typically have high individual interest and are engaged in highly-interesting experiential activities, our findings suggest that they may still benefit from periodic utility value reflections.

7.9 Acknowledgments

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7.11 Tables and Figure

Table 7.1. Schedule of experimental procedures.

Wk.[1]	Int.[2]	Survey	Objective
1			
2		X	Test pre-class individual interest, verify covariate balance across treatment and control groups
3			
4			
5	X		
6	X	X	Test situational interest, validate treatment administration
7	X	X	Test situational interest, validate treatment administration
8			
9	X		
10			
11			
12	X	X	Test situational interest, validate treatment administration
13	X		
14			
15		X	Test long-term effects of interventions on situational interest and individual interest
16			

[1]Week of the 16-week semester.
[2]This column denotes dates when we administered treatments (either a control picture summarization task or a utility value reflection) to students.

Table 7.2. Response rates for control and utility value reflection groups across four experimental timepoints.

Survey	Week	UVR (n)	CTRL (n)	Total (n)	Total (%)[1]
Pre	1	39	34	73	100.0
Period 1	6	36	28	64	87.7
Period 2	7	36	35	71	97.3
Period 3	12	36	33	69	94.5
Period 4/Post	15	39	34	73	100.0

[1]Response rates presented as a percentage of the post-survey respondents.

Table 7.3. Demographic information of control and utility value intervention groups with Chi-squared and Welch's two-sample t-tests for independence from the treatment condition (N = 73).

Parameter	UVR	CTRL	χ^2	*t*	*df*	*p*
Pre-test						
Individual interest[1]	6.1 (0.8)	6.3 (0.7)		0.9	70.4	.36
Early performance						
First exam	73.8 (9.5)	76.8 (11.8)		1.2	63.3	.25
First 5 lab quizzes	8.3 (0.8)	8.2 (0.9)		-0.4	66.9	.72
Period 4/Post-test						
Female	31 (79.5%)	25 (73.5%)	0.1		1	.75
Underrepresented minority[2]	5 (12.8%)	7 (20.6%)	0.3		1	.56
First generation 4-year degree	50 (34.0%)	24 (18.5%)	1.6		1	.21
Parents' highest education[3]	Bachelor's	Bachelor's				

[1]Pre-test individual interest is an average of responses to eight items on a 1 to 7 Likert scale.
[2]Based on the U.S. Census Bureau definition, we considered students selecting any the following options as their dominant racial/ethnic identity as underrepresented minorities: black or African American, Hispanic or Latino, American Indian or Alaska Native, or Asian.
[3]Ordered options: "None of the above, high school diploma or equivalency, Associate's degree, Bachelor's Degree, Master's Degree, Doctorate or Professional Degree."

Table 7.4. Brief descriptions of utility value reflection and control conditions adapted from Hulleman et al. (2010).

Utility Value Reflection (UVR)	Control – Picture Summarization (CTRL)
Learners given prompt: Write a short 1-3 paragraph essay (5+ sentences per paragraph) describing the potential relevance of this material to your own life, or to the lives of other people. Please focus on how this technique could be useful to you or other people and give examples.	**Learners given prompt**: Write a short 1-3 paragraph essay (5+ sentences per paragraph) on the objects you see in the pictures. Describe in detail the objects you see in front of you.

Table 7.5. Themes discovered in utility value reflection responses and representative quotes, categorized within task value components.

Utility Value	
Career plans	"As a food scientist, I would need to understand the production side of animal products."
Academic plans	"I will eventually have to take ANSC 221 and I feel this information will be help"
Hobbies or future hobbies	"I want to raise rabbits and goats in the future"
Altruism	"If I go on a mission trip this could help me determine if the dairy in that area is safe to consume"
Family/friends	"I have family that has horses. Therefore if they ever need my help I will know what to do."
Not valuable based on career plans	"I do not think I will have any relationship to this industry in my professional life."
Intrinsic Value	
Intrinsic value	"Most importantly, I love animals and I enjoy understanding aspects of the animal industry" "Seeing the different caging systems definitely fascinated me."
Meaningful past experiences	"I grew up raising horses and helping my grandpa feed, wash, brush, and other horse maintenance"
Attainment value	
Idealized self	"This information will help me to be the best student and future vet possible"
Self-development	"…it is important to learn about things that make you uneasy, as you are able to create more empathy and understanding for people and worlds that are different from your own."
Obligation to animals	"This is the beginning of a new life. You need to make sure the baby lives a good healthy life." "Mastitis is uncomfortable. It would be best if I could help prevent or treat the infection before it progresses."
Obligation to advocate/represent agriculture	"I want to have a well-rounded knowledge about all things agriculture so that I can teach people about all the good things that agriculturalists do."

Table 7.6. Linear mixed model describing situational interest across four experimental periods.

Predictors	Situational Interest[1] Estimates	*p*
(Intercept)	31.0	<.001
Pre-test individual interest	5.9	<.001
Score on first exam	0.1	.97
Score on first five lab quizzes	0.5	.72
First-generation	1.3	.64
Female	1.4	.64
Underrepresented minority	-0.5	.89
Utility-value reflection (UVR)	5.3	.06
Period 2	3.1	.09
Period 3	0.2	.92
Period 4	-1.6	.40
UVR * Pre-test individual interest	-4.9	.05
UVR * Period 2	-2.2	.38
UVR * Period 3	-2.2	.38
UVR * Period 4	-0.9	.72
Random Effects		
σ^2	51.0	
$\tau_{00\ student}$	72.7	
$ICC_{student}$	0.59	
$N_{student}$	73	
Observations	277	
Marginal R^2	0.15	
Conditional R^2	0.65	

[1]Coefficients represent situational-interest-squared, transformed from a scale from 1 (low) to 7 (high).

[2]The σ^2 and τ_{00} represent the within-group and between-group variance, respectively. $ICC_{student}$ shows the intraclass-correlation coefficient for the random intercept of student.

Table 7.7. Kendall and point-biserial correlations among treatment, interest variables, and course performance (N = 73 students).

*p-value <0.01
**p-value <0.001

	Parameter	1	2	3	4	5	6	7	8
1	UVR	1	.15	-.11	.10	-.07	-.02	.04	-.14
2	Situational interest[1]		1	0.10	.49**	.02	-.03	.01	-.03
3	Pre-test individual interest			1	.34*	.18	.18	.10	.14
4	Post-test individual interest				1	.11	.11	.11	.07
5	Overall course grade					1	.68**	.47**	.64**
6	Overall lab quiz score						1	.59**	.49**
7	Score on first 5 lab quizzes							1	.39**
8	Score on first exam								1

[1]Situational interest is averaged over four experimental periods.

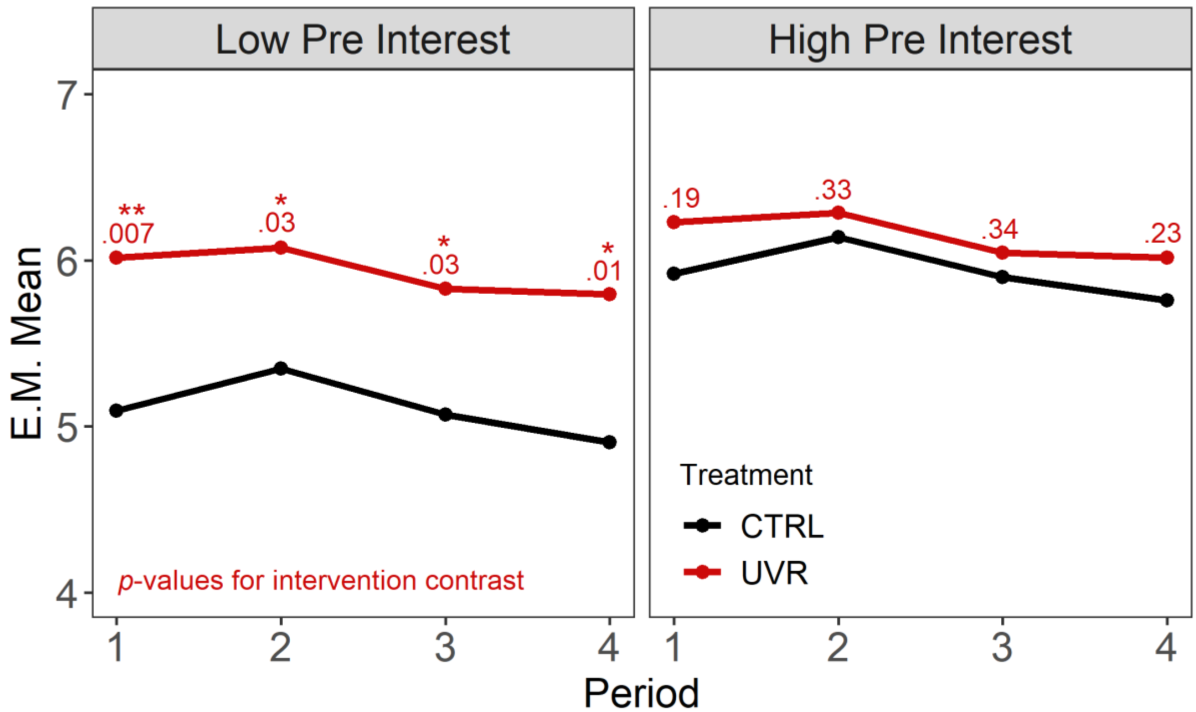

Figure 7.1. Estimated marginal means and standard errors for situational interest for control (CTRL) and utility value intervention (UVR) groups conditioned on low and high pre-test individual interest. Pre-test individual interest was trichotomized at threshholds of 6.0 and 6.6 based on a scale 1-low to 7-high. The four experimental periods represent weeks 6, 7, 12, and 15 of the 16-week semester. Situational interest is expressed on the original scale (1-low to 7-high). Significant one-sided post-hoc Tukey's tests are denoted with asterisks (*p < .05, **p < .01).

CHAPTER 8. LONGITUDINAL MEASUREMENT INVARIANCE AND STABILITY OF INDIVIDUAL INTEREST ACROSS A 16-WEEK INTRODUCTORY ANIMAL SCIENCES COURSE

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8.1 Abstract

Educators often compare quantitative scores on motivational traits across time (e.g. pre- and post-semester), yet few studies have examined the longitudinal measurement equivalence of such traits or described typical trajectories. Our research explored the longitudinal measurement of individual interest in two cohorts of an introductory animal sciences course across four measurement occasions during a 16-week semester. First, we modified an existing individual interest scale and validated it within our population (CFI = 1.00, SRMR = 0.02, RMSEA = 0.05). Second, we established partial scalar invariance across measurement occasions through nested model comparisons. Third, we described the trajectory of individual interest with latent growth curve models (LGCM). Individual interest started high for both cohorts (intercepts = 65.02, 61.06 on a scale from 0 (low) to 70 (high) for Fall 2018 and Spring 2019, respectively). Individual interest followed a curvilinear pattern in Fall 2018, however, no significant shape trends described Spring 2019 data. Overall, our results show that individual interest can be measured equivalently across a semester, however, it follows heterogenous trajectories. Further research is needed to improve the sensitivity of individual interest scales within high-interest populations and relate heterogenous interest trajectories to classroom experiences.

8.2 Introduction

Previous authors have described introductory science courses as a volatile landscape for individual interest development (Suresh, 2006). On the one hand, introductory courses may lead students to deepening and formalizing their interest in a particular subject matter (Harackiewicz, Smith, & Priniski, 2016; Kyndt et al., 2015). On the other hand, they often function to "weed out" potential students who—for better or worse—find the course and its topics uninspiring (Sithole et al., 2017). Indeed, studies have shown that processes of motivation and achievement differ substantially across students with heterogenous personal, psychosocial, and socioeconomic profiles (Martens & Metzger, 2017; De Clerq, Galand, & Frenay, 2020). Although recent work has advanced theoretical understanding of interest in science undergraduates (O'Keefe, Dweck, & Walton, 2018), operationalized science-specific forms of interest as measurable constructs (Knetka, Rowland, Corwin, & Eddy, 2020; Lamb, Annetta, Meldrum, & Vallett, 2012), and related interest to science introductory course experiences (Erickson, Marks, & Karcher, 2020), limited existing research addresses issues associated with measuring interest. For example, many experimental and observational studies are premised on the implied assumption that interest can be measured equivalently across sampling periods (e.g. pre- and post-semester) and/or student characteristics. Given that interest has been described as a relational, dynamic construct at the intersection of person and environment, however, it theoretically may shift form amid varying personal or contextual characteristics (Ainley, 2017). Sources of longitudinal interest variation include conceptual recalibration (beta change), reconceptualization (gamma change), and true quantitative changes in interest (alpha change); each of which has different implications for measuring and managing interest in the classroom (Golembiewski, Billingsley, & Yeager., 1976). Additional work exploring the quantitative measurement of interest is needed to elucidate its dynamics in science educational settings and facilitate efforts to target it as a learning outcome. The present research explores the longitudinal measurement of individual interest in introductory animal science undergraduates across a semester-long course.

8.2.1 Theoretical Framework

Interest is a powerful motivator of learning, engagement, and achievement that takes several forms (Harackiewicz, Smith, & Priniski, 2016). In their influential Four-Phase Model of Interest Development, Hidi and Renninger (2006) distinguish two main functional forms of interest: situational and individual. Situational interest is a dynamic, multidimensional construct triggered by the immediate features of a task or environment (Chen, Darst, & Pangrazi, 2001; Erickson et al., 2020). In contrast, the present study deals with individual interest. Individual interest is a relatively stable disposition to re-engage with a particular subject matter that develops slowly--representing interest's crystallization as an aspect of identity and personality (Harackiewicz, Smith, & Priniski, 2016).

Recent work has empirically confirmed theoretical relations between individual and situational interest. For example, Rotgans and Schmidt (2017) showed that repeated experiences of situational interest can lead to the development of individual interest. Knogler, Harackiewicz, Gegenfurtner, and Lewalter (2015) used a latent state-trait model to show that situational interest is context-specific. Within the context of animal sciences, past work has shown that interest remains relatively stable across introductory course experiences (Erickson, Guberman, Zhu, & Karcher, 2019) and that various active learning modalities can prompt varying levels of situational interest (Erickson et al., 2020). However, to our knowledge, no prior work has explored the longitudinal measurement invariance and stability of individual interest across an introductory course.

8.2.2 Context in Animal Sciences

Individual interest has assumed particular importance as an assessment outcome in undergraduate animal science education in recent years as the demographics of enrollees changes (Erickson et al., 2019; Lyvers-Peffer, 2011; Reiling, 2003). As fewer Americans experience animal agriculture during childhood and adolescence, fewer opportunities exist for developing individual interest in the subject prior to collegiate study (Dimitri, Effland, & Conkin, 2005). This creates barriers to successful adaptation to animal science industry and academic careers, where practitioners share a strong social identity (Erickson et al., in press). Accurate quantification of individual interest development during undergraduate animal science education therefore has implications for improving equitable access to our discipline through a variety of pathways.

8.2.3 Purpose

This study investigates the measurement properties of Linnenbrink-Garcia et al.'s (2010) individual interest scale and describes individual interest development within undergraduate animal science students during a 16-week course. The following three objectives guided our research:

1. Validate the unidimensional Individual Interest Questionnaire (IIQ) proposed by Linnenbrink-Garcia et al. (2010) within introductory animal science students using a confirmatory factor analysis.

2. Test the temporal measurement invariance of individual interest over four timepoints during the semester.
3. Describe the trajectory of individual interest over four timepoints during two cohorts of an introductory course.

8.2.4 Context and Participants

This research focuses on students in ANSC 10200, Introduction to Animal Agriculture, a 16-week medium- to large-enrollment introductory course taught at a Midwestern land-grant university. Historically, the course has consisted primarily of first-year and pre-veterinary students with relatively little experience in animal sciences (Erickson et al., 2019). Course sessions include twice-weekly 50-minute lectures and a weekly 110-minute laboratory session. The total sample of participants in this study includes approximately 284 undergraduate students from two introductory animal sciences courses taught by two separate instructors at a large Midwestern university. The sample consisted primarily of females and the majority of students were Caucasian (Tables 1 and 2).

8.3 Methods

8.3.1 Research Design

The Institutional Review Board approved all study procedures. A graduate laboratory coordinator and a total of 11 undergraduate TAs (2-3 per laboratory section) facilitated the course's five laboratory sessions and carried out experimental procedures for this study. At the beginning of the semester (Period 0) students completed an outside-of-class pre-questionnaire.

At three timepoints during the semester (Period 1-3), students completed a survey assessing their individual interest at the beginning of the course laboratory session. The final week of the semester, students completed a survey with individual interest and demographic questions outside of class (Period 4). Table 2 shows the exact timing of survey administration, which varied slightly from the spring to fall semester but remained aligned with similar course laboratory topics.

8.3.2 Instrumentation

To measure individual interest, we selected a questionnaire conceptually aligned with our operationalization of interest development at the academic discipline level: Linnenbrink-Garcia and colleagues' (2010) theoretically unidimensional eight-item Individual Interest Questionnaire (IIQ; Appendix 1). Linnenbrink-Garcia et al. (2010) adapted the IIQ from the task value scale of Pintrich et al.'s (1993) Motivated Strategies for Learning Questionnaire, observing it to be highly reliable ($\alpha = 0.90$) and empirically distinct from situational interest in undergraduate psychology. We adapted wording to make items specific to our context (e.g. "Animal sciences is practical for me to know"). Students responded to all items via a Qualtrics form using a sliding scale from 0 (strongly disagree) to 70 (strongly agree) during experimentation (Qualtrics, Provo, UT). Because the pre-test used a Likert scale with radio buttons 1 to 7, responses were excluded from measurement invariance testing but rescaled and incorporated into latent growth analysis. Descriptive statistics across each period are presented in Table 4.

8.3.3 Statistical Analysis

We conducted all statistical analyses in R (R Core Team, 2019) using primarily the lavaan and semTools packages (Jorgensen, Pornprasertmanit, Schoemann, & Rosseel, 2019; Rosseel, 2012) and declaring significance at $p<0.05$. To handle missing data, we used the Full Information Maximum Likelihood (FIML) Estimator suggested by Arbuckle (1996). Compared with listwise deletion, FIML has been shown to produce less-biased parameter estimates (Ferro, 2014). Similar to Linnenbrink-Garcia et al. (2010), our IIQ responses violated multivariate normality assumptions (Curran, West, & Finch, 1996). To accommodate, we used maximum likelihood estimation with robust Huber-sandwich estimation of standard errors (Huber, 1967; White, 1980). Likewise, we compared nested models using the scaled difference in the log likelihood chi squared statistic ($\Delta\chi^2$) and absolute differences in alternative fit indices (AFIs). The $\Delta\chi^2$ represents the standard approach, while AFIs are modern alternatives that have the advantage of being independent of sample size. Fit indices included the scaled root mean squared error of approximation (RMSEA; Steiger, 1989), the scaled comparative fit index (CFI; Hu & Bentler, 1999), the standardized root mean square residual (SRMR; Hu & Bentler, 1999), gamma hat ($\hat{\gamma}$; West et al., 2012), and McDonald's noncentrality index (MFI; McDonald, 1989). Per the recommendations of Cheung and Rensvold (2002), we considered $\Delta CFI \geq 0.01$, $\Delta\hat{\gamma} \geq 0.001$, and $\Delta MFI \geq 0.02$ as indicative of significant differences in nested model fit. We constructed diagrams with the "semPlot" package (Epskamp, 2019).

8.4 Results

8.4.1 Single-Group Confirmatory Factor Analysis

To validate the measurement model within our population and check for problematic items, we fitted preliminary CFA models on a subset of data from experimental period 2 (Figure 1; Table 5). We selected period 2 due to the high response rate and the synchronicity of its timing across semesters. The initial model fit the data poorly and modification indices revealed two problematic indicators, “II.2” and “II.4” (Awang, 2012). Both indicators were significantly and highly correlated with other indicators on the scale but had higher error variance and lower loadings. Because ancillary parallel analyses suggested a one-factor solution and only two indicators were problematic, we removed items and proceeded with a reduced unidimensional scale rather than attempting to fit two- or three-factor models. The revised model showed excellent fit (Hu & Bentler, 1999; Tabachnick & Fidell, 2007).

8.4.2 Longitudinal Measurement Invariance

Next, we began testing the measurement invariance across time. First, we examined a configural model that simultaneously estimated four correlated factors representing each of the measurement periods. We standardized factor means and variances to 0 and 1, respectively, to identify the model (Reise, Widaman, & Pugh, 1993). We freely estimated loadings, intercepts, and the residual covariances between each indicator across experimental periods. The configural model showed adequate fit (Table 6) and inspection of modification indices did not reveal logical opportunities for respecification. Consequently, we concluded that configural invariance requirements were satisfied and moved forward with constraining additional parameters.

Next, we constrained each item's factor loadings to equality across experimental periods to test metric invariance. In this model, we again fixed the latent factor means to 0 and the variance of the factor representing the first experimental period to 1. However, we freely estimated variances for subsequent experimental periods (Johnson, Meade, & DuVernet, 2009). The metric invariance model showed adequate fit (Table 6) and did not differ significantly from the configural model on the basis of the $\Delta\chi^2$ (Counsell, Cribbie, & Flora, 2020). This indicated metric invariance, i.e., the equivalence of the contribution of each indicator to the latent factor over time. We subsequently proceeded to fitting a scalar invariance model.

Finally, we tested a scalar invariance model by constraining indicator intercepts to equality across each experimental period. In this model, we fixed the mean and variance of the latent factor representing the first experimental period to 0 and 1, respectively, and freely estimated means and variances for factors representing experimental periods 2, 3, and 4. This model constrained factor loadings and intercepts for all indicators to equality across time but allowed free estimation of residual variances. The $\Delta\chi^2$ indicated significantly poorer fit of the scalar compared with the metric invariance model. Comparing model alternative fit indices showed mixed results, with ΔCFI and ΔMFI indicating scalar invariance and $\Delta\hat{\gamma}$ suggesting scalar noninvariance. As a result, we sequentially removed constraints on equality of intercepts for the most non-invariant items to test a partial scalar invariance model (Partial Scalar Item-wise). Releasing the constraints on items 1 and 3 produced a model that satisfied not only ΔCFI and ΔMFI requirements but also the $\Delta\chi^2$ test. We therefore concluded that the IIQ was at least partially temporally invariant in our sample, i.e., that the majority of indicators functioned similarly over the four measurement periods.

Because our data were not missing completely at random, we examined the possibility that unique and missing responses at period 4 had altered scalar invariance results. To do so, we released equality constraints and freely estimated intercepts for all indicators on period 4. All other model parameters were estimated as described in the initial scalar invariance model above. The model (Partial Scalar Period-wise) did not show substantially improved fit on the basis of $\Delta\chi^2$ and ΔAFIs compared with the metric model. Because this model had the same degrees of freedom as the Item-wise Partial Scalar model, we therefore concluded that noninvariance in means of items 1 and 3 throughout the semester contributed more substantially to total scale noninvariance than did noninvariance in means of all items on experimental period 4.

8.4.3 Longitudinal Descriptive Statistics

Having established partial measurement invariance, we next explored the trajectory of individual interest throughout the semester in both our fall and spring classes (Table 7). Responses were skewed toward the upper end of the scale throughout the semester for both cohorts. Although graphical visualization revealed substantial between-subjects variation in growth trajectories (e.g. Figure 2), slight negative trends appeared present for both cohorts. To explore whether trends represented statistically-significant group-level phenomena, we next fitted latent growth curve models.

8.4.4 Latent Growth Curve Model

To explore group-level patterns in individual interest across time, we estimated latent growth curve models (LGCM) of the standard form described by Duncan and Duncan (2009) in which the intercepts, variances, and covariance of latent intercept and slope parameters are freely estimated while intercepts of manifest variables (individual interest at each sampling) are fixed to zero and factor loadings on the latent variables are fixed to numeric weights (Figure 3; McArdle & Bell, 2000). Because sampling timing differed for Fall 2018 and Spring 2019 cohorts, we estimated two separate models and interpolated linear and quadratic slope weights scaling time in 1-week units. We again accounted for missing data by employing the FIML estimator (Arbuckle, 1996). In each cohort, our sample size and observations per individual satisfied the recommended minima proposed by Curran, Obeidat, and Losardo (2010). However, we computed Willett's (1989) growth rate reliability (GRR) to estimate statistical power to detect slope variance for each LGCM.

For both cohorts, we explored a series of nested models estimating: 1) a latent linear growth term and intercept, 2) latent linear and quadratic growth terms and intercept. To identify the second model, we assumed homoscedasticity of time-specific residual variances and constrained them to equality. Inspection of model estimates and BIC indicated that the second form of model better described the data from both cohorts.

A LGCM with both linear and quadratic growth terms described the Fall 2018 data well (Table 8). Model results imply that individual interest started high on average (intercept of latent intercept) albeit with significant variation around the starting point (variance of latent intercept). Individual interest growth during the semester was significantly predicted by positive linear and slight negative quadratic time terms (linear and quadratic intercepts). However, significant latent variances for both growth terms signaled heterogeneity in growth paths between individual students. Neither linear nor quadratic growth terms covaried significantly with the intercept, indicating that the initial level of individual interest had no bearing on growth observed. Willett's (1989) GRR was >0.99 for each Fall 2018 measurement occasion suggesting excellent reliability.

Taken together, these results suggested that individual interest in the Fall 2018 cohort started high and followed a curvilinear trend, unaffected by starting level but varying significantly between individuals.

LGCM approximated the Spring 2019 data poorly. A significant intercept implied that individual intercept started at the upper range of the scale. However, we discovered no significant shape trends. Residual variances and global fit indices showed poor model fit with the data. In addition, Willett's (1989) GRR ranged from 0.30 to 0.70 for each measurement occasion, indicating poor reliability of the LGCM. Although the sample size of the Spring 2019 cohort was roughly half that of the Fall 2018 cohort, the large fraction of residual variance indicated that misfit derived from misspecification—the linear and quadratic shape parameters did not describe the data well. Although it is possible to specify more complex shape parameters in LGCM, this approach extended beyond our objectives and was not suggested by our data (Ning & Luo, 2017). As a result, we concluded that Spring 2019 individual interest showed no consistent shape patterns and its trajectory was obscured substantially by both within- and between-individual variation.

8.5 Limitations

Before findings are discussed in detail, several limitations of our research warrant discussion. First, our research examined a sample with limited diversity from one introductory course at one university. As such, the generalizability of our results is restricted to similar populations. Second, we assumed data were missing at random and used a model-based estimator to account for missing responses. Although missing data and FIML estimation are both standard in longitudinal studies, non-monotone missingness can bias parameter estimates (Ferro, 2014). Third, our experiment assessed narrow aims related to measurement invariance over the course of the semester. We had insufficient power to test measurement invariance between semesters or along other dimensions such as culture and gender (Kline, 2005). Future studies with larger, more diverse samples or employing different experimental design (e.g. staggered survey administration) may more precisely model other possible sources of noninvariance. A further limitation of our study is its reliance on self-report data. Although self-report measurement is standard in interest literature, it nonetheless relies on participants' metacognitive awareness of their interest and is susceptible to certain testing effects (Renninger & Su, 2012). Future studies examining multiple sources of information from multiple data collection methods may enhance the trustworthiness of results from the revised IIQ.

Additionally, our research raised serious questions regarding the sensitivity of the IIQ and the treatment of individual interest scores as continuous responses. Our data were negatively skewed with a large proportion of observations at the upper limit. Censoring of responses at the upper end of the scale reduces both the content validity of the IIQ and its sensitivity within highly interested populations. Additional scale development work may improve researchers' ability to differentiate students at high levels of individual interest. For existing IIQ data, it may be sensible to treat responses as ordinal and fit structural models with Muthén & Muthén's (2007) weighted least squares with means and variances adjusted estimator (Li, 2016). When considering longitudinal IIQ data, which likely involves not only censored responses but also between-person heterogeneity of growth trajectories, latent class growth analysis, growth mixture models, and Tobit growth models may provide superior predictive accuracy and reduced bias compared with traditional LGCM (Feng, Hancock, & Harring, 2019; Grimm & Ram, 2009; McArdle & Anderson, 1990).

8.6 Discussion

Our research examined the measurement of individual interest over four testing periods during the semester of an introductory animal science course. Although interest has assumed importance as an educational outcome and teaching quality indicator in animal sciences, limited research has assessed issues related to its measurement. Our research addressed three such aims: 1) validity and reliability of a modified individual interest scale within the animal science context, 2) measurement equivalence of the individual interest scale across a 16-wk introductory course, and 3) patterns in mean individual interest (i.e. “alpha change) over time.

First, our initial single timepoint confirmatory factor analyses extended past research (Linnenbrink-Garcia et al., 2010) to a new population—showing the revised IIQ to be a valid and reliable measure of individual interest in animal science undergraduates after removing two problematic items. Second, similar to past research, which has demonstrated the temporal measurement equivalence of closely related constructs such as intrinsic and extrinsic motivation throughout the first year of university study (Brahm, Jenert, & Wagner, 2017), we found that the revised IIQ achieved partial scalar invariance over four measurements during the semester. This indicates that the measurement properties of most revised IIQ indicators do not change substantially over time and composite scores can capture true changes in individual interest across measurement occasions (i.e. “alpha change”; Brown, 2006; Golembiewski, Billingsley, & Yeager, 1976).

However, pursuant to our first and second objectives, CFA and measurement invariance analyses discovered several items that were inconsistent within (II.2 and II.4) and between (II.1 and II.3) time periods, which we addressed by reducing the scale and freeing model constraints. However, more research is warranted to understand why these items produced erratic responses and to determine if replacement or additional items can improve the validity and reliability of the IIQ. Notably, the inconsistent items discovered in the initial CFA (II.2 and II.4) align conceptually with the non-invariant items (II.1 and II.3) discovered in subsequent analysis: all focus on individual interest's value and identification dimensions (Harackiewicz & Hulleman, 2010). In contrast to the enjoyment-focused items (II.5 through II.8) which appear relatively consistent, these value- and identification-focused items functioned inconsistently across students and time.

This differential functioning, in part, may be traceable to discipline-based differences. For example, the immediate practical relevance of animal science may appear uncertain for students who leave family farms or other animal-based employment to pursue undergraduate degrees, or those with relatively little prior animal experience (Fraser, 2010). Similarly, social identification with animal sciences likely differs from that with psychology, the disciplinary context in which the IIQ was developed. Animal science is a broad, heterogenous discipline in which subgroup membership may be more salient to identity—in other words, a student might identify more strongly as a swine scientist than an animal scientist (Stets & Burke, 2000). Indeed, Knogler and colleagues (2015) highlighted the narrowness of content breadth in individual interest as potentially incongruous with acknowledging its development from situational sources. Operationalizing individual interest as broader and more tied to action (e.g. Lawless & Kulikowich, 2006) may improve test sensitivity. These issues draw attention to a need to develop individual interest measures that accurately reflect the complex social and personal value animal science holds for its diverse undergraduate constituents.

Finally, our third objective involved profiling individual interest across a semester-long introductory course through LGCM. Past research has shown growth in the individual interest of primary school students over four weeks when situational interest is repeatedly stimulated (Rotgans & Schmidt, 2011). In contrast, Frenzel. Goetz, Pekrun, and Watt (2010) described curvilinear declines in interest as middle school students studied mathematics over four years. Our results showed that individual interest was fairly stable and generally concentrated at the upper end of the scale but varied substantially between individuals. Additionally, we detected significant linear and quadratic shape trends for the Fall 2018 but not Spring 2019 cohorts. One potential source of this discrepancy may be differences in teacher, student, and course characteristics. Fall 2018 and Spring 2019 cohorts were taught by different instructional teams, leading to slight variation in the course content and teaching style. Different students comprised each cohort, and class sizes were smaller in Spring 2019 (~20 vs. ~37 per laboratory). Contextual factors likely also differed between cohorts. For example, many fall semester enrollees took the course during their first semester of undergraduate study as they transitioned to college life. In contrast, most spring semester enrollees entered the course with at least 1 semester of prior experience.

Our study is not the first to describe heterogeneous, non-linear motivational growth in first-year students. For example, in a 25-month study spanning the transition from secondary to higher education across a range of disciplines, Kyndt et al. (2015) fit models describing slopes for autonomous motivation growth that differed across five timepoints. De Clerq, Galand, and Frenay (2020) and Martens and Metzger (2017) illustrated that the development of academic motivation differs substantially across student groups of varying personal, psychosocial, and socioeconomic characteristics. As Hofer (2010) points out, individual interest forms amid a network of diverse, often conflicting goals and personal experiences. It is possible that major life events such as the adjustment to college influence the trajectory of individual interest independently or in concert with course experiences.

8.7 Conclusions

A revised version of the individual interest instrument from Linnenbrink-Garcia et al. (2010) demonstrated excellent reliability and validity with animal science introductory course students after removing two problematic items. Additionally, the revised IIQ exhibited partial scalar invariance over four measurement occasions throughout a semester of instruction, indicating that mean differences can capture true changes in individual interest over time. However, further research on the psychometric properties of individual interest scales is warranted to improve sensitivity in high-interest populations and measurement validity of value/identification dimensions. With respect to interest trajectories, LGCM showed that group mean individual interest during a Fall 2018 cohort started high and followed a curvilinear trend. However, LGCM of a Spring 2019 cohort detected no significant linear or quadratic shape trends across subjects and showed substantial between-subjects variation in growth trajectories. Interest development during undergraduate study likely follows heterogenous paths which can represent both spurious between-person differences and structural forces. More longitudinal research is warranted to understand the complexity of individual interest's trajectory during undergraduate study and its interconnections with other developmental processes (e.g. knowledge and skill development), personal characteristics (e.g. achievement-related beliefs), behavior patterns (e.g. course-taking, performance-approach goals), and achievement outcomes (e.g. graduation, GPA).

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8.9 References

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8.10 Tables and Figures

Table 8.1. Demographic characteristics of n = 246 students (86.6% response rate) and their n = 491 reported parents/guardians.

Category	Count
Parent/Guardian Highest Education[1]	
Bachelor's degree (BS)	167
High school diploma or equivalency (GED)	147
Master's degree (MS)	76
Associate degree (AS)	47
Professional (MD, JD, DDS, etc.)	18
Doctorate degree (PhD)	13
Other (please specify)	13
None of the above (less than high school)	10
Student Gender Identification	
Female	193
Male	51
Other/Prefer not to respond	2
Student Racial and Ethnic Identity[2]	
White	218
Hispanic or Latino	21
Asian	10
Black or African American	10
Native Hawaiian or Other Pacific Islander	2
Other	2
American Indian or Alaska Native	1

[1]Highest education denotes the final formal schooling received.
[2]Students self-described racial and ethnic identity through a “SELECT ALL” question.

Table 8.2. Experimental schedule, response count, and response rate for the Fall 2018 and Spring 2019 semesters.

	Cohort					
	Fall 2018			Spring 2019		
Period	Wk.	n	%	Wk.	n	%
0	1	147	79.0%	1	91	92.3%
1	4	164	88.2%	6	87	88.8%
2	7	158	84.9%	7	92	93.9%
3	9	159	85.5%	12	93	94.9%
4	15	157	84.4%	15	78	79.6%
Total Unique		186	100.0%		98	100.0%

Table 8.3. Frequencies of missing data patterns across the four experimental periods. N = 284 students.

Period					N
Pre	1	2	3	4	
1	1	1	1	1	183
1	1	1	1	0	24
0	1	1	1	1	4
0	1	1	1	0	18
1	1	0	1	1	7
1	1	0	1	0	1
0	1	0	1	1	1
0	1	0	1	0	1
1	0	1	1	1	9
1	0	1	1	0	2
0	0	1	1	0	1
1	0	0	1	1	1
1	1	1	0	1	8
1	1	0	0	1	2
1	1	0	0	0	1
0	1	0	0	1	1
0	0	1	0	0	1
0	0	0	0	1	19
46	33	34	32	49	

Note. Pattern expressed as 1 = present, 0 = missing for periods 1, 2, 3, and 4.

Table 8.4. Raw descriptive statistics item-by-item for the individual interest questionnaire (IIQ) for each of the four experimental periods.

Item \ Period	1		2		3		4		All	
	M	SD	*M*	SD	*M*	SD	*M*	SD	Skew.	Kurt.
II_1	63.2	14.6	64.4	10.9	61.9	13.4	62.2	13.2	-2.7	0.4
II_2	52.4	18.4	57.7	15.6	57.2	16.7	54.3	17.2	-1.3	0.5
II_3	60.6	14.5	61.5	12.8	60.2	14.6	58.8	15.5	-1.9	0.4
II_4	56.8	17.4	59.6	14.5	59.2	15.1	56.9	17.3	-1.6	0.5
II_5	65.1	11.7	64.7	10.1	63.1	12.3	62.8	12.4	-2.9	0.4
II_6	65.8	10.4	65.0	10.0	63.5	11.8	63.3	12.9	-3.0	0.4
II_7	65.1	10.8	64.4	10.2	62.9	12.5	62.0	13.3	-2.7	0.4
II_8	64.3	12.3	64.6	10.0	62.1	13.9	61.8	13.7	-2.6	0.4

Note: *M* = Mean, SD = standard deviation, skew. = skewness, kurt. = kurtosis. Table 1 presents response rate and count for each period.

Table 8.5. Standardized results of initial and revised CFA models for the Individual Interest Questionnaire on experimental period two. N = 254 students.

	Initial Model[1]			Revised Model		
	Est.	SE	*P*	Est.	SE	*P*
Factor Loadings						
II.1	0.85	0.13	<0.001	0.84	0.13	<0.001
II.2	0.59	0.08	<0.001			
II.3	0.77	0.09	<0.001	0.75	0.09	<0.001
II.4	0.72	0.09	<0.001			
II.5	0.89	0.12	<0.001	0.90	0.12	<0.001
II.6	0.93	0.13	<0.001	0.94	0.13	<0.001
II.7	0.93	0.12	<0.001	0.94	0.12	<0.001
II.8	0.92	0.11	<0.001	0.93	0.11	<0.001
Residual Variances						
II.1	0.28	0.06	<0.001	0.30	0.07	<0.001
II.2	0.65	0.10	<0.001			
II.3	0.40	0.08	<0.001	0.44	0.09	<0.001
II.4	0.48	0.08	<0.001			
II.5	0.20	0.10	0.049	0.19	0.10	0.054
II.6	0.13	0.04	0.005	0.11	0.04	0.005
II.7	0.13	0.03	<0.001	0.12	0.03	<0.001
II.8	0.14	0.04	<0.001	0.14	0.04	0.001
Fit Indices						
$\chi 2$	111.21***			10.65		
df	20			9		
CFI	0.88			1.00		
SRMR	0.08			0.02		
RMSEA	0.22			0.05		

[1]Est. = estimate, S.E. = standard error, *p* = p-value.
Note. Scaled values are presented for CFI, RMSEA, and χ^2.

Table 8.6. Measurement invariance models for the Individual Interest Questionnaire (IIQ) of n = 284 students across four experimental periods throughout the semester.

	Fit Index[1]							
	df	RMSEA	CFI	SRMR	$\hat{\gamma}$	MFI	χ^2	Δdf
Configural	210	0.07	0.91[a]	0.09	0.913[a]	0.274[a]	556.04[A]	
Metric	225	0.07	0.90[a]	0.09	0.913[a]	0.256[a]	572.00[A]	15
Scalar	240	0.07	0.90[a]	0.09	0.908[b]	0.248[a]	608.84[B]	15
Partial Scalar (Item-wise)	234	0.07	0.90[a]	0.09	0.911[b]	0.255[a]	589.61[A]	9
Partial Scalar (Period-wise)	234	0.07	0.90[a]	0.09	0.908[b]	0.248[a]	597.56[B]	9

[1]df = degrees of freedom, RMSEA = root mean square error of approximation, CFI = comparative fit index, SRMR = standardized root mean square residual, MFI = McDonald's non-centrality index

Note. Capital superscripts represent pairwise differences at $p<0.05$. Lowercase superscripts indicate pairwise differences based on Cheung and Rensvold (2002) proposed cutoffs. Scaled values are presented for df, CFI, RMSEA, and χ^2.

Table 8.7. Descriptive statistics for individual interest of n = 284 students before and during four experimental periods throughout the semester.[1,2]

	Cohort	
Period	Fall 2018 (n = 186)	Spring 2019 (n = 98)
Pre-test	64.7 (60.0 - 69.6)	61.8 (58.0 – 69.6)
1	66.4 (65.0 – 70.0)	61.8 (59.0 – 70.0)
2	66.1 (65.5 - 70.0)	61.5 (57.2 – 70.0)
3	65.0 (63.5 – 70.0)	57.2 (51.7 – 70.0)
4	62.3 (59.8 – 70.0)	59.9 (55.4 – 70.0)

[1]Mean (first quartile – third quartile)
[2]Rated on a continuous scale from 0 (strongly disagree) to 70 (strongly agree) corresponding to low and high individual interest, respectively.

Table 8.8. Latent growth curve models of individual interest in two cohorts of an introductory animal sciences course (Fall, N = 186; Spring, N = 98).

	Fall 2018[1]			Spring 2019		
	Est.	S.E.	*p*	Est.	S.E.	*p*
Factor Loadings (Linear)						
Pre	0.00+			0.00+		
1	3.00+			5.00+		
2	6.00+			6.00+		
3	8.00+			11.00+		
4	14.00+			14.00+		
Factor Loadings (Quadratic)						
Pre	0.00+			0.00+		
1	9.00+			25.00+		
2	36.00+			36.00+		
3	64.00+			121.00+		
4	196.00+			196.00+		
Residual Variance						
Each	11.16	1.99	<0.01	52.72	17.64	<0.01
Intercepts						
Intercept	65.02	0.46	<0.01	61.56	0.89	<0.01
Linear	0.47	0.13	<0.01	-0.13	0.27	0.62
Quadratic	-0.05	0.01	<0.01	-0.01	0.02	0.77
Variances						
Intercept	24.77	6.25	<0.01	22.91	20.52	0.26
Linear	1.43	0.41	<0.01	0.94	1.79	0.60
Quadratic	0.01	0.00	<0.01	0.00	0.01	0.91
Covariances						
Int. w/ Linear	-0.47	1.65	0.78	9.51	5.55	0.09
Int. w. Quadratic	0.06	0.11	0.58	-0.54	0.34	0.11
Linear w. Quadratic	-0.09	0.03	<0.01	-0.03	0.13	0.81
Fit Indices						
χ^2 (Scaled)	10		<0.01	10		<0.01
CFI	0.95			0.89		
TLI	0.95			0.89		
RMSEA	0.09			0.09		

+Fixed parameter

[1]Est. = estimate, S.E. = standard error, *p* = p-value.

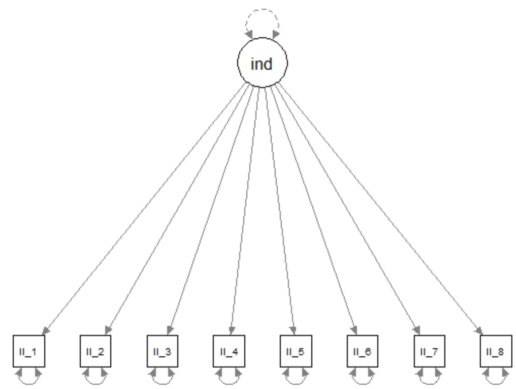

Figure 8.1. Proposed measurement model for individual interest.

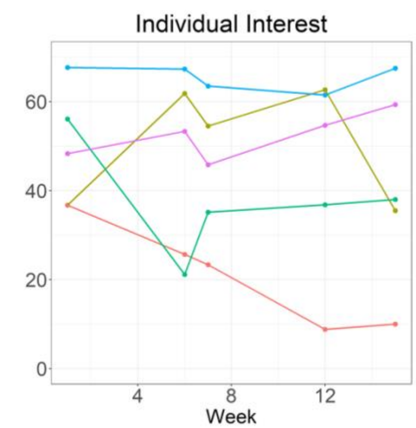

Figure 8.2. Semester-long individual interest profiles of selected students, demonstrating heterogeneous growth patterns (n = 5).

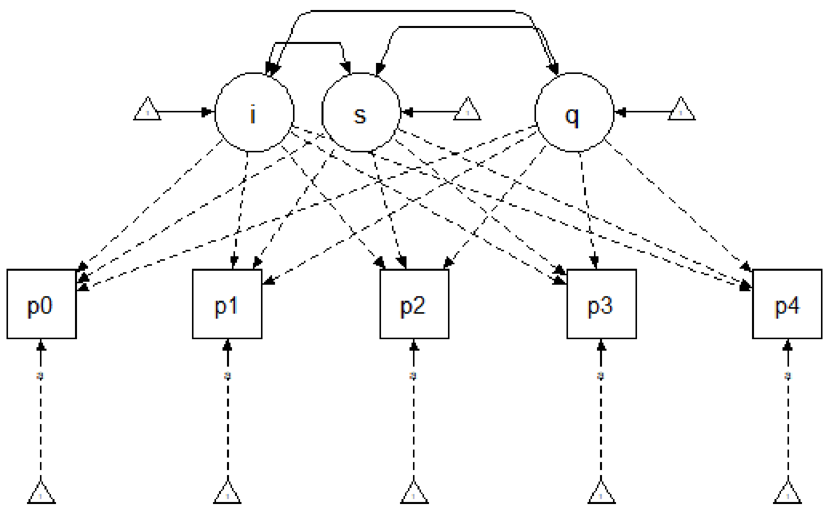

Figure 8.3. General form of latent growth curve models for individual interest during the semester. Latent linear growth, quadratic growth, and intercepts are denoted by “s”, “q,” and “i,” respectively.

8.11 Appendix

Individual Interest Questionnaire

1. Animal sciences is practical for me to know.
2. Animal sciences helps me in my daily life outside of school.
3. It is important to me to be a person who thinks like an animal scientist.
4. Thinking like an animal scientist is an important part of who I am.
5. I enjoy the subject of animal sciences.
6. I like animal sciences.
7. I enjoy doing animal sciences activities.
8. Animal sciences is exciting to me.

CHAPTER 9. PRACTICES AND PERCEPTIONS AT THE COVID-19 TRANSITION IN UNDERGRADUATE ANIMAL SCIENCE COURSES

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9.1 Abstract

The swift transition to remote learning in response to the COVID-19 pandemic presented substantial challenges for both students and instructors in post-secondary natural sciences education. To examine teaching practices and student engagement during the emergency remote learning in the Spring 2020 semester, we surveyed 10 instructors and 261 students in an animal and dairy sciences department at a large Midwestern university. Instructors reported using a diversity of teaching practices. On average, students perceived high teaching presence and cognitive presence and moderate social presence during emergency remote learning. Student-reported educational experience differed substantially between courses and explained a significant amount of variance in student engagement and satisfaction outcomes ($p<0.001$). Open-ended responses revealed beliefs and attributions about remote learning that shaped students' interpretations of educational experiences. Results support the validity of the Community of Inquiry (CoI) framework for assessing emergency remote learning and suggest future research on modulators of social presence.

Abbreviations:

CI, confidence interval; CoI, community of inquiry; CFI, comparative fit index; FIML, full-information maximum likelihood; CFA, confirmatory factor analysis; M, mean; RMSEA, root mean square error of approximation; SD, standard deviation; SE, standard error; SRMR, standardized root mean square residual; TA, teaching assistant; TLI, Tucker-Lewis index; TPI, Teaching Practices Inventory

9.2 Introduction

In the Spring 2020 semester, instructors coordinated massive efforts to adapt natural sciences courses to remote learning in response to COVID-19 restrictions (Sutton & Jorge, 2020). Nearly one year later, online and remote instruction are forecasted to remain dominant undergraduate teaching modalities at many U.S. universities (The College Crisis Initiative, Nov., 2020). Although technology-integrated pedagogies have developed substantially in natural sciences education in the past decade, the shift to remote instruction during the Spring 2020 semester occurred with unanticipated urgency and magnitude. In coping with this challenge, instructors and students formed new norms, values, and beliefs about online and remote learning that have implications for the viability of these teaching modalities in the mid-pandemic and post-pandemic university paradigm (Hodges, Moore, Locke, Trust, & Bond, 2020).

For many institutions, the sudden transition to remote teaching constituted a prolonged emergency. Capacity for remote teaching depends on information and communication technology infrastructure; available training, support, and funding; institutional and departmental teaching culture; student preparedness for remote learning; and faculty workload and motivation, among other factors (Knysh & Dudziak, 2020; Meyer & Xu, 2007). In past research, instructors reported that teaching online imposed a substantial workload above teaching in-person, typically requiring weeks or months more preparation (Freeman, 2015). This suggests that during the Spring 2020 semester, instructors dedicated substantial time above their contractual obligations to adapt to emergency remote instruction. To our knowledge, research summarizing the emergency remote teaching practices used by natural sciences educators is still forthcoming.

In addition to faculty and institutional factors, student personal and social factors are critical determinants of the remote learning environment. In early reports, students described diverse personal concerns affecting their educational experience during spring 2020 emergency remote learning. Ramachandran and Rodriguez (2020) list altered living or financial conditions, difficulties focusing, technology/network issues, and mental health as common student-reported concerns. Research showed that students from low-income households and racial/ethnic minorities were more likely than white or high-income students to report connectivity issues affecting their learning (Means & Neisler, 2020). Although a great deal of research suggests that online and blended learning can be as effective as in-person instruction (Veneri & Ganotti, 2014), even for complex practical skills (McCutcheon et al., 2014) it is unclear whether emergency remote teaching practices achieved similar positive outcomes during Spring 2020 (Jeffery & Bauer, 2020).

Natural sciences educators are in uncharted territory in the COVID-19 world. A great deal more research is needed to understand how instructional systems responded to initial challenges, how such systems are reaching new equilibria with remote and blended learning, and how universities can continue their missions to educate, empower, and serve given the shifting educational paradigm. As a preliminary observational study, we surveyed instructors and students in an animal and dairy sciences department regarding emergency remote teaching in the Spring 2020 semester. The present study describes instructors' emergency remote teaching practices, student perceptions of educational experience, and student outcomes related to engagement and satisfaction.

9.2.1 Research Design and Questions

Our research used a mixed-method, concurrent nested design (Creswell, 2015). We surveyed ten agriculture instructors and 261 students during the Spring 2020 semester addressing research questions in the following four categories:

1. **Perceived preparedness.** To what extent were students and instructors prepared for a sudden transition to remote learning?
2. **Remote teaching practices.** During the Spring 2020 semester, what instructor practices and priorities characterized typical remote classes?
3. **Student perceived educational experience.**
    a. How did students rate their Spring 2020 experience of social presence, cognitive presence, and teaching presence in online communities of inquiry?
    b. How were student perceptions of social presence, cognitive presence, and teaching presence influenced by student demographics and classroom-level variance?
4. **Student engagement and satisfaction outcomes**. How were student outcomes of satisfaction and perceived change in engagement (relative to prior the pandemic) related to student demographics, educational experience, and classroom-level variance?

Figure 1 shows a conceptual model of proposed relationships among instructor, course, and student variables considered in the present study. Due to the small number of instructors involved in the study, our focus on instructor practices was descriptive. Our analysis focused on student-level rather than classroom-level variance because the low number of classes provided insufficient power to separate out classroom-level effects. However, when considering student variables, we considered variance between courses as a proxy for differences attributable to varying learning environments and instructional practices. Additionally, we investigated relationships among student perceptions of educational experience to student personal variables including demographics and engagement and satisfaction outcomes.

9.3 Methods

9.3.1 Context and Participants

Our research took place at a large, Midwestern university (Carnegie Basic classification: Doctoral Universities, Very High Research Activity). We surveyed ten instructors of ten mid- to upper-level (150-400 level) animal science courses conducted during the spring 2020 semester, and 261 student respondents across these courses (Table 1). All instructors of all surveyed courses responded. In the single case where an instructor taught more than one course, they completed a single questionnaire applying to both courses. A course with contributions from two faculty members provided two separate instructor survey responses which we retained. In general, student response rates were excellent. In the few cases that student response rates were poor, we retained data from instructor respondents for its value to our first three objectives.

Table 2 summarizes the demographics of student respondents. Most students identified as racial/ethnic non-minorities and roughly a quarter reported that neither of their parents/guardians had completed a 4-year degree. A majority identified urban communities as their familial hometowns. Females comprised nearly three-quarters of the sample. Students were distributed across year classifications and represented animal science, dairy science, and a variety of other majors.

9.3.2 Survey Procedures

The Institutional Review Board supervised all study procedures (Protocol #2020-0032). All surveys were administered in the window from 04/23/2020 to 05/10/2020 through an online survey platform (©Qualtrics, Provo, UT). On 04/23/2020, we distributed both instructor and student surveys simultaneously to instructors. Instructors were responsible for administering student surveys in their classes and offering a small incentive (0.5% extra credit) for completion. Instructors did not receive compensation for completing instructor surveys. After the end of the semester, we provided instructors deidentified reports summarizing student survey results in their course(s).

9.3.3 Instrumentation

Instructor Survey

Our instructor survey included the following components: 1) basic information including the course title and number of students enrolled, 2) inventories of updates and accommodations provided during adaptation and remote teaching developed by the research team, 3) questions about the extent of video-conferencing use, typical activities in synchronous video-conferenced courses, and technologies used, generated by the research team, 4) selected items from Wieman and Gilbert's (2017) Teaching Practices Inventory (TPI) representing the structure of supplementary materials, assignments, and feedback in the course, and 5) items modified from the TPI inventorying collaborative teaching approaches utilized during remote teaching, and 6) a brief validity check. In addition, after each section, instructors were asked to rate whether they perceived "positive," "negative," or "neutral" effects on this category during remote learning compared with previous semesters. Items consisted of rating scales, "select all" questions, and open-ended questions.

In the brief validity check, six out of ten instructors reported that the instructor survey "very" or "extremely" accurately and completely captured their teaching method and response to the pandemic on a 5-point scale. Four instructors selected that the survey instrument was "slightly" or "moderately" accurate and complete in describing their teaching. In open-ended responses, instructors elaborated that additional inquiry should more specifically address the needs of laboratory-based and large enrollment courses and the time requirements for preparing online instructional materials.

Student Survey

We based assessments of students' remote learning experience on the Community of Inquiry (CoI) framework scale developed by Arbaugh et al. (2008). The three-factor scale corresponds to three facets of educational experience: social presence, cognitive presence, and teaching presence. Each CoI factor separates qualitatively into subscales (Table 3). Students rated the 34 items in the CoI questionnaire on a 5-point scale from "strongly disagree" to "strongly agree."

In addition to assessing students' perceived educational experience during emergency remote learning, we evaluated two variables we considered more distal, interpretive outcomes: 1) satisfaction with emergency remote learning and 2) perceived change in engagement during emergency remote learning compared to prior in the semester. We assumed that both demographic and CoI educational experience variables would contribute to students' reported satisfaction and change in engagement outcomes. Students rated their satisfaction with remote learning on a 5-point Likert scale from "extremely dissatisfied" (1) to "extremely satisfied" (5). Students rated perceived change in engagement by selecting "more engaged," "less engaged," or "neutral," and optionally elaborating in an open-ended response. One member of the research team triangulated student responses to rating scales and open-ended responses, showing excellent agreement.

9.3.4 Statistical Analysis

We conducted all statistical analyses in R and declared significance at $p<0.05$ (R Core Team, 2020). We computed summary statistics using base R and "dplyr" functions (Wickham, François, Henry, & Müller, 2020). We fit a confirmatory factor analysis (CFA) in "lavaan" (Rosseel, 2012). We retained only the first response for students who provided responses in multiple courses, leaving N = 261. Due to moderate skewness and kurtosis in teaching presence and cognitive presence variables, we used maximum likelihood estimation and robust Huber-sandwich estimation of standard errors (Huber, 1967; White, 1980). Fit indices included the scaled comparative fit index (CFI), the Tucker-Lewis index (TLI), the scaled root mean squared error of approximation (RMSEA), and the standardized root mean square residual (SRMR). The CFA indicated adequate reliability and validity of the community of inquiry questionnaire in our sample after allowing correlations between two item residuals within each factor (CFI = 0.89; TLI = 0.89; RMSEA = 0.06; SRMR = 0.06).

For regression modeling, our unit of analysis was student within course. Before fitting regression models, we prepared data in several steps. To avoid imbalance in random effect group sizes, we deleted responses from two courses that had two or fewer student respondents (courses I and J) leaving 257 responses. For parsimony, we dichotomized predictor variables major (animal and dairy science majors vs. non-majors), gender (male vs. female and non-binary / not-specified), racial and ethnic identification (white vs. underrepresented minority), community type (rural vs. urban), and first-generation college student (yes vs. no) and recoded with dummy contrasts based on reference groups suggested by the literature. Classification (freshman, sophomore, junior, senior, graduate/non-traditional) was treated as a factor.

To fit regression models, we used the lme4 package (Bates, Maechler, Bolker, & Walker, 2015). Following the recommendation of Barr, Levy, Scheepers, and Tily (2013), we fit random effects structures with the maximum complexity justified by the data and experimental design. In most cases, this amounted to a random intercept for "course" to account for non-independence. Due to modest sample size, we did not consider interactions between predictors (Leon & Heo, 2009). We retained all demographic and educational experience predictors in models regardless of significance due to their theoretical importance. We checked for multicollinearity of predictors and homoscedasticity of residuals by computing variance inflation factors and inspecting residual plots, respectively.

9.3.5 Qualitative Analysis

To recover additional explanatory data, one researcher analyzed instructor and student qualitative responses using a rapid coding approach (Taylor, Henshall, Kenyon, Litchfield, & Greenfield, 2018). To protect the confidentiality of instructor participants, course and instructor information were removed from qualitative data before analysis. All instructor respondents and a fraction of student respondents (M = 14.5%, SD = 0.07% within the n = 8 courses modeled) provided qualitative data. Following Fereday & Muir-Cochrane's hybrid approach (2006), analysis consisted of two stages. In the deductive stage, we applied a codebook based on the dependent variables in our conceptual model and summarized data into relevant categories. In the inductive stage, we re-analyzed responses within categories without an *a priori* framework, searching for explanatory factors with practical relevance to stakeholders. After defining *a posteriori* codes, we applied these codes to the data to identify inductive themes within deductive categories. We paraphrased themes and selected exemplary quotes to present in the results section.

9.4 Results & Discussion

9.4.1 Perceived Preparedness

Most instructors (n = 6) rated their course as "not at all" or only "slightly" online-ready prior to the Spring 2020 semester, reporting that some course materials and assignment submissions had been online prior to the Spring 2020 semester. Most instructors (n = 7) had no or little experience with online teaching before adapting their courses. Likewise, 72.6% of students reported having little to no experience with taking courses taught predominantly online.

Pre-pandemic studies documented resistance toward remote education among faculty in colleges of agriculture and natural sciences (Boland, 2017; Roberts, Moore, & Dyer, 2005). Although educational technologies are increasingly central to higher education's value proposition, most instructors have limited experience teaching and learning in online courses

(Marek, 2009; Horvitz, Beach, Anderson, & Xia, 2015). Research suggests that under typical conditions, online courses require more time to develop and implement compared with in-person instruction, and this is especially true for instructors with little experience teaching remotely (Freeman, 2015). Still, even prior to the pandemic, distance education was growing rapidly as a mode of instruction in higher education. The National Center for Educational Statistics (NCES, 2019) reported that in 2018, roughly a third of students were enrolled in at least one remote learning course at U.S. post-secondary institutions. Still, only 16.6% of students were enrolled in exclusively remote learning courses (NCES, 2019). This research is consistent with our finding that most students and instructors were relatively inexperienced with remote education and coped with an unprecedented challenge to adapt to the Spring 2020 emergency remote learning circumstances.

9.4.2 Remote teaching practices

The adaptation process

Many instructors provided students with accommodations and support while adapting to online learning (Table 4). In an open-ended response, one instructor expressed a preference for open, informal communication with students during the transition to remote learning, remarking that students were "already inundated with information" from other courses. Instructors used a variety of university-licensed (Canvas, Blackboard Collaborate, Webex) and independent (Zoom, personal website, other) technologies to teach remotely. Instructors reported moderate satisfaction (Dissatisfied, $n = 1$; Neutral, $n = 4$; Satisfied, $n = 5$) with the performance of these technologies during remote teaching.

Due to the unprecedented impacts of the COVID-19 pandemic on students' day-to-day lives, the literature provides relatively few descriptions of appropriate accommodations. Our results indicated that most instructors were flexible and accommodating to student needs during emergency remote learning, which Petillion and McNeill (2020) suggested aligns with student preferences. The majority of instructors used the dominant instructional technologies supported by the university, suggesting that institutional support plays a critical role in faculty technology adoption (Marek, 2009).

In-class engagement

Most instructors expected students to prepare for in-class engagement during emergency remote learning (Table 5). Nine of 10 instructors reported that instructor-created content (e.g. slides, worksheets, self-authored papers) played the most central role in their courses, above instructor independent content (materials from external sources, not the instructor or students) and student-created content (e.g. student projects, presentations, summaries). In an open-ended response, one instructor remarked that the abrupt change to remote teaching necessitated a more instructor-dominant approach but that they saw potential for more student-centered remote teaching in future iterations.

The range of practices used by instructors in our sample suggests a continuum from traditional lecture-based, instructor-dominant instruction to flipped-classroom, student-centric approaches (Mok, 2014). In our sample, most instructors appeared nearer to the traditional lecture-based approach, although instructor use of pre-class and reflective assignments suggested some use of student-centered learning strategies. Research has related assignments prompting metacognition, self-guided inquiry, reflexivity, and interaction with students and instructors with student engagement and performance in online coursework (Gray & Diloreto, 2016; Vincent, Pilotti, & Hardy, 2016; Kahn, Everington, Kelm, Reid, & Watkins, 2017; Garcia-Vedrenne, 2020). However, building such assignments into coursework requires time, advance planning, and input from students—all of which instructors lacked during the Spring 2020 semester (Wurdinger & Allison, 2017; Ramachandran & Rodriguez, 2020). In non-emergency situations, instructors can likely leverage student-centric assignments to greater engagement and learning gains.

Asynchronous and synchronous approaches

Of 10 instructors surveyed, six used synchronous video-conferences to replace a significant portion of course activities, with the remainder posting narrated slide decks for students to view asynchronously. Several instructors using synchronous video-conferences noted that the allocation of time for various synchronous activities in their course was moderately different during remote teaching than in previous semesters ($n = 4$). Approaches to video-conferenced classes varied among instructors (Figure 2).

Results showed a dominance of instructor-centric, lecture-based teaching strategies during synchronous session in emergency remote learning. This is consistent with research describing typical university science teaching prior to the pandemic (Stains et al., 2018). Aside from two instructors who used a variety of student-centered strategies in courses J, D, and G, our results showed underutilization of strategies that engage students in synchronous sessions (McBrien, Cheng, & Jones, 2009). Additionally, results showed that few instructors chose to teach asynchronously, which may have stemmed from intentions to ease students’ transition to emergency remote instruction during the Spring 2020 semester. Although each strategy requires a drastically different approach, research has shown that asynchronous and synchronous instruction can achieve similar engagement, satisfaction, and learning outcomes for students compared with in-person instruction (Neuhauser, 2002; Somenarain, Akkaraju, & Gharbaran, 2010). However, regardless of teaching approach, lecture-based instruction typically produces lower engagement and learning compared with student-centered techniques (Erickson, Marks, & Karcher, 2020; Freeman et al., 2014). As Jeffery and Bauer (2020) suggest, building capacity for remote learning in the long-term will require more substantial departmental and institutional support for implementing student-centered instruction.

Table 6 summarizes the use intensity of various video-conferencing features by instructors teaching synchronous video-conferenced classes. All instructors reported using the chat box nearly every class. Instructors reported using Google Docs or other synchronous workspaces, polls, breakout groups, and virtual whiteboards less frequently or not at all. In open-ended responses, instructors shared limitations associated with the chat box ("too distracting"), the breakout rooms (inability to pre-assign groups), and the virtual whiteboard (difficult to draw smoothly).

Supporting materials

Table 7 describes the supplemental materials available to students during remote teaching. Nearly all instructors reported providing lecture notes or recorded slide decks. Half or fewer indicated providing additional resources such as articles from related academic literature, grading rubrics, discussion boards, worked examples, and examples of exemplary projects. The majority of instructors (n = 7) stated that their use of supplemental materials was "about the same" during remote teaching compared with prior in-person semesters. The remaining instructors reported perceiving either positive (n = 1) or negative (n = 2) effects of remote instruction on their use of supplemental materials.

In recent studies, many instructors adopted multipronged, multimodal teaching strategies to avoid inequities due to student circumstances (e.g. connectivity) during the Spring 2020 semester (Czerniewicz et al., 2020). Our results showed that most instructors provided a range of supplementary materials to accompany synchronous or asynchronous course sessions, although instructors did not report substantial changes in supplementary materials following the pandemic. In the TPI, Wieman and Gilbert (2014) suggest that in general, providing more and higher quality supporting materials is associated with greater student success. In non-emergency situations with more time for advance preparation, natural sciences educators may have adequate time and resources to enhance the supporting materials provided to students for remote instruction.

Assignments and feedback

Table 8 describes the structure of assignments and feedback in remote courses. The majority of instructors assigned regular graded homeworks or problem sets at intervals of 2 weeks or less. No instructors reported using homeworks or problem sets that did not contribute to course grades. Fewer than half of the courses involved student-driven papers or projects or group assignments. Most instructors (n = 8) indicated that the quality of students' assignments was about the same during remote teaching as during previous semesters. However, one instructor who reported a decline in the quality of assignment submissions associated with remote learning opined that a lack of structure with remote teaching caused students to approach coursework less systematically.

Regarding feedback to students, most instructors indicated providing graded midterms and graded assignments for students to review (Table 8). A minority of instructors offered online office hours or explicitly encouraged students to meet with them. Although six instructors indicated that feedback in the course was "about the same" as prior semesters, another three mentioned that remote teaching hindered their ability to provide students with feedback. In open-ended responses, one instructor mentioned that students "respond better in an in-person meeting for dialogue about study/learning challenges." Another suggested that they "couldn't engage with students before or after class…and mentor students."

The nature and frequency of interactions with faculty and other students shape undergraduates' personal, social, and academic outcomes (Cotten & Wilson, 2006). At present, it is unclear how emergency remote teaching affected instructors' interactions with students in and out of class, although pre-pandemic research found that students' use of virtual and in-person office hours was similar (Li & Pitts, 2009). Indeed, virtual feedback systems may be preferable to in-person systems for certain students (Kelly, Keaten, Hazel, & Williams, 2010). Wieman and Gilbert (2014) recommend that more frequent, more collaborative assignments and more feedback from instructors are associated with improved student outcomes.

Learning how to teach remotely

Table 9 shows instructors' self-reported strategies used to transition to remote teaching. Most instructors discussed the process of adapting courses to remote and remote teaching practices with colleagues. Many described attending university- and/or corporate-sponsored training for remote teaching, and half reported consulting the literature. A minority of instructors indicated that they had turned to blogs, websites, or other informal resources. No instructors reported sitting in on colleagues' classes to learn ideas. Importantly, several courses were co-taught with other faculty (n = 3), undergraduate student teaching assistants (TAs; n = 3), and graduate student TAs (n = 4) such that the instructor felt a shared responsibility to adapt to remote instruction (n = 3). Nearly all instructors (n = 9) reported that their collaborative teaching efforts were "about the same" during remote teaching as with prior semesters. The remaining instructor felt remote teaching positively affected their collaborative teaching.

Our results indicate that instructors drew from a diversity of sources to adapt to emergency remote teaching but did not seek support from colleagues or the broader teaching community to a great extent. This is consistent with reported pre-pandemic behavior of instructors in our sample and with research showing that faculty typically collaborate to a lesser extent on teaching than on research or service activities (Joseph, Oh, & Ackerman, 2018; Ramsden, 1998). In non-emergency settings, faculty collaboration in scholarship of teaching and learning or peer support networks has been shown to develop pedagogical knowledge, improve technical competencies, and facilitate sharing of resources (Roxå, Olsson, and Martensson, 2008; Kyei-Blankson, Keengwe, & Blankson, 2009; Erickson, Guberman, & Karcher, 2020). In the long term, natural science educators can accelerate the development of remote and blended instruction by expanding and strengthening teaching collaborations. Critically, institutions and departments must create teaching culture and support systems to unlock the capacity-building benefits of collaborative teaching (Wingo, Ivankova, & Moss, 2017).

9.4.3 Student Educational Experience

Table 10 shows student self-rated educational experience based on the Community of Inquiry framework questionnaire (Arbaugh et al., 2008). Responses centered at the upper range of the scale for all subscales. The high mean observed across CoI subscales in our sample during emergency remote learning is comparable to values achieved in typical online courses (Kozan & Richardson, 2014; Diaz, Swan, Ice, & Kupczynski, 2010). This result was unexpected considering the inexperience of instructors in our sample with remote teaching, and previous research which showed that the degree of instructor experience with online teaching has a significant positive correlation with teaching presence and cognitive presence (Arbaugh, 2008).

Cronbach's alpha coefficients corroborated the reliability of subscales (Arbaugh, Bangert, & Cleveland-Innes, 2010). Notably, greater means were associated with teaching presence and cognitive presence subscales compared with the social presence subscales. This is consistent with instructors' reported instructor-dominant teaching practices. The highest-rated subscale, design & organization, indicated that students in our sample perceived that instructors very clearly communicated course topics, course goals, due dates, and instructions. High ratings on resolution suggested that students perceived that the course developed their abilities to apply knowledge learned. Conversely, students rated social presence subscales group cohesion and affective expression nearer to neutral. Neutral affective expression indicated that participants may not have felt a sense of belonging in the course or experienced positive interactions with other course participants (Garrison & Aykol, 2013). Neutral group cohesion indicates that participants may not have developed a sense of collaboration, trust, or respect through participation in the course. In our sample, subscales with lesser means generally showed greater standard deviations, which may represent actual differences or the artifactual ceiling imposed by Likert scale response options.

Table 11 presents linear mixed-effects regressions with CoI scales social presence, cognitive presence, and teaching presence as dependent variables, demographic predictors as fixed effects, and course as a random intercept. We found no demographic predictors significantly predicted CoI scale variables during emergency remote learning. This is in contrast with past research in which the demographics such as ethnicity, gender, and discipline significantly impacted CoI variables in online courses (Dempsey & Zhang, 2019; Wicks, Craft, Mason, Gritter, & Bolding, 2015) and past research showing demographic differences in students' adaptability to online learning (Xu & Jaggars, 2013). It is plausible that our sample lacked the diversity and sample size to make differences apparent, or that the accommodations and multimodal support provided by instructors created equitable learning environments.

In our study, restricted maximum likelihood (REML)-based likelihood ratio model comparisons indicated that the random intercepts for course explained a significant proportion of the variance in CoI scales ($p<0.001$). The marginal coefficient of determination (R^2) shows the variance attributable to only the fixed effects, whereas the conditional R^2 shows the variance attributable to both fixed and random effects (West, Welch, & Galecki, 2014). Intra-class correlation coefficients (ICC) show the within-course similarity of CoI variables. Results presented in Table 11 suggest that instructor and student factors specific to the course influenced social presence, cognitive presence, and teaching presence in our sample. Our study is the first to our knowledge to report variance component estimates describing students' educational experience in remote courses within a single university department. However, our results were consistent with Wilson, Summers, and Wright (2020) in which multi-level modeling showed significant faculty impacts on student educational experience in seven in-person courses within a single university department. In line with past research on in-person instruction, our findings showed that instructors significantly impact student perceptions of the classroom cognitive presence, social presence, and teaching presence which has implications for student educational experience and satisfaction outcomes (Burgess, 2018; Umbach & Wawrzynski, 2005).

In open-ended responses, students discussed ways in which remote learning affected their educational experience. For social presence, several submitted that their emergency remote learning courses lacked opportunities for interaction, e.g., “the lectures were recorded which made it difficult to ask questions…I expect to have an opportunity to converse with my professor during class time,” and “It was more difficult to understand what was being emphasized within presentations without being able to see the professors’ faces.” Other students discussed the difficulty of engaging in discussions with peers online (particularly when all videos are turned off) and holding peers accountable virtually. For cognitive presence, students mentioned difficulties self-motivating, focusing, and keeping up with scheduled assignments. For teaching presence, students shared appreciation for instructors who communicated regularly, used technology seamlessly, established accommodation policies, created accountability structures, organized course materials, and provided multimodal learning resources. Several students described competing interests (employment and family), internet connectivity issues, and mental health concerns further affecting their educational experience. Conversely, one student who described commuting to class prior to the pandemic noted that remote learning “saved me time and stress.” Although no demographic variables significantly predicted quantitative engagement metrics across our student sample, qualitative results reinforce that certain students felt their educational experiences were shaped by non-academic factors during emergency remote learning (Petillion & McNeill, 2020; Ramachandran & Rodriguez, 2020).

9.4.4 Student Satisfaction and Engagement Outcomes

Satisfaction with emergency remote learning

Table 12 presents a linear mixed-effects regression relating students' satisfaction with emergency remote learning to predictors representing student personal information and course perceptions. On average, students reported being "neither satisfied nor dissatisfied" with emergency remote learning (M = 3.4, SD = 1.1). Meta-analytical research has shown that student satisfaction may be reduced for synchronous and asynchronous remote courses compared with in-person courses (Ebner & Gegenfurtner, 2019; Lowenthal, Bauer, & Chen, 2015). However, the particular factors causing differences in satisfaction are unclear. At this stage, we included demographic variables to control for direct effects outside of CoI variables and found no significant associations. However, perceived social presence had a strong positive influence on student satisfaction. These results are consistent with past research showing that social presence strongly predicts learners' satisfaction with remote learning as a learning modality (Arbaugh & Benbunan-Fich, 2007) and satisfaction with remote courses (Choy & Quek, 2016; Lee, Looi, Faulkner, & Neale, 2020). This may reflect the larger variance in social presence relative to cognitive presence and teaching presence in our sample. Our study assumed that students' perceived CoI experience in a course, unmeasured variables, and their interpretations would contribute to their satisfaction with emergency remote learning. However, the large amount of variance explained by the CoI variables relative to the variance attributed to the random effect of course indicates that the CoI framework explained most course-related variance in satisfaction in our sample. This result suggested that the CoI is a promising framework to capture differences in instructor- and course-level variation relevant to student-reported satisfaction at the end of the semester.

A dominant theme related to satisfaction in student open-ended responses described students adjusting expectations. For example, students adjusted expectations to match the course's pre-pandemic format, e.g., "[this] wasn't a course that had an abundance of student-professor or student-student interaction in the first place"; to match perceived limits of remote learning, e.g. "my dissatisfaction with remote learning is not due to my professors in any way and I do not know what they could have done to make it better."; and to match experiences in other courses in which they were currently enrolled, e.g. "I felt that this class had the smoothest transition to online learning out of all the classes I am in this semester." Conversely, other students expressed dissatisfaction in relation to unadjusted expectations. For example, "I was really looking forward to the labs associated with this course…I feel a bit robbed of the experience," "I feel conned out of thousands of dollars, and cheated out of what could have been a fantastic class," and "If I found it more enjoyable and engaging I would have paid to go to an online school." Several students showed empathy toward instructors, recognizing their substantial efforts to adapt instruction in adverse circumstances. Taken together, quantitative and qualitative data related to satisfaction suggest that both educational experiences and students' interpretations shape satisfaction with emergency remote learning. Perceived social presence exerted a strong positive influence on student satisfaction, however, students adjusted expectations using various reference points. Given the uncertainty at many institutions surrounding "the new normal," varying expectations may continue to convolute student satisfaction with remote learning in future semesters. As Hodges et al. (2020) suggest, early experiences and interpretations with remote learning have implications across remote, blended, and online learning.

Perceived change in engagement during emergency remote learning relative to prior

Table 13 shows a generalized linear regression with a logit link describing the relative risk of students reporting losing engagement during emergency remote learning. Of 257 student respondents, 134 (52.1%) reported a negative effect of emergency remote learning on their engagement compared with prior in the semester, while 113 (44.0%) and 10 (3.9%) reported neutral and positive effects, respectively. This is consistent with the expectation that traumatic, unexpected changes have negative impacts on student engagement (Wang et al., 2020). Although we first fit a mixed model to describe change in engagement, this produced a singular fit. Per Barr, Levy, Scheepers, and Tily (2013), we removed the random term to allow a non-singular fit and estimated a logit-link generalized linear model. At this stage, we included demographic variables to control for direct effects outside of CoI educational experience variables and none significantly predicted the odds of losing engagement. However, each point increase in perceived social presence was associated with significantly reduced odds of reporting losing engagement during emergency remote learning. Teaching presence was a marginally significant predictor of reduced odds for losing engagement. These results again reinforced the explanatory power of the CoI framework for distal outcomes such as engagement and satisfaction, and the importance of social presence in remote learning educational experience (Khalid & Quick, 2016; Lee et al., 2020).

Nearly a third of open-ended responses represented a theme we termed “student beliefs about engagement in remote learning.” Overwhelmingly, students shared that they believed remote learning to be a less-engaging modality compared with in-person. One student suggested that they required physical classroom attendance to feel engaged. Several issued judgments on the unsuitability of particular courses to remote learning. In open-ended responses, student beliefs about remote learning appeared independent of educational experiences, e.g., “[My professor] did a great job of adjusting. Online learning simply doesn’t work well for me.” Only one respondent demonstrated reflexive awareness that “it is not ideal to be forced to take online classes when you are used to in-person instruction.” Based on open-ended data, negative beliefs about engagement in remote learning may represent a substantial hurdle in creating engaging remote educational experiences (Xie & Huang, 2014). Although we did not investigate instructor beliefs and attributions, research suggests that instructors’ mindsets influence teaching practices and may also be an important topic for research (Aragón, Eddy, & Graham, 2018).

9.5 Limitations

Our study has at least four important limitations. First, we used a convenience sample representing a limited group of instructors and students within a single department at a single university. A fraction of our target sample did not provide responses to surveys. Inference outside our population will require future meta-analytic work or cross-sectional research with more advanced sampling designs. Second, we relied on self-report measures of teaching practices and student educational experience (Douglass, Thomson & Zhao, 2012). To avoid potential biases of self-report data, future researchers might capitalize on the richness of behavioral data captured through learning management systems and in course recordings (Wichadee, 2014). Third, our research is observational and does not prove causal links among variables studied. We recommend future experimental work manipulating teaching practices or

CoI variables in varying contexts (Oncu & Cakir, 2011). Fourth, we surveyed students and instructors during a disruptive semester and used theoretical frameworks and instrumentation developed prior to the pandemic (Wang et al., 2020). At present, it is unclear to what extent Spring 2020 semester patterns are comparable to pre-pandemic studies or research developed in the later stages of adaptation.

9.6 Conclusions

As natural sciences instructors adapt to mid-pandemic and post-pandemic teaching, our results provide evidence that instructors with limited remote teaching experience can create equitable remote learning environments fostering social presence, cognitive presence, and teaching presence—even amid challenging global and institutional circumstances. In our study of emergency remote learning in Spring 2020, social presence varied the most between courses and predicted student outcomes of satisfaction and perceived change in engagement relative to in-person instruction. Open-ended responses revealed how students' individual experiences were affected by expectations and beliefs about remote learning. Our cross-sectional, self-report study assessed a limited population of instructors and students in an animal and dairy science department during a disruptive semester. In the long-term, more research is needed to develop mid-pandemic and post-pandemic natural science pedagogies that satisfy student needs in varying institutional and departmental contexts.

9.7 Recommendations

Our results suggest the following actions for natural science educators teaching remote or hybrid courses:

1. Surmount new challenges by relying on a community of colleagues with experience, if not expertise, in remote teaching and learning.
2. Build social presence by crafting spaces for participatory learning, authentic self-expression, and interpersonal interactions.
3. Engage students cognitively by offering them multiple ways to learn (multi-modal teaching) and plentiful supporting resources.
4. Maintain strong teaching presence by establishing clear goals, policies, and accommodations for the course.
5. Be conscious of instructor and student beliefs and expectations surrounding remote learning and confront any that detract from learning and satisfaction.

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9.10 Tables and Figures

Table 9.1. Distribution of student and instructor respondents across courses and course types.

Course	Instructor Respondents (n)	Student Respondents (n)	Student Enrollment (n)	Student Response Rate (%)
A	1	114	143	79.7
B	2	46	50	92.0
C	1	42	60	70.0
D	1	26	28	92.9
E	1	24	31	77.4
F	1	23	26	88.5
G	1	18	24	75.0
H	1	4	8	50.0
I	1	2	29	6.9
J	1	1	20	5.0
Total	10	300	419	71.6

Note: Courses D and G were taught by one instructor who provided a single response applying to both courses. 300 total student responses represent 261 distinct students who took multiple surveys representing different courses in which they were enrolled.

Table 9.2. Demographics of student sample (N = 261).

Demographic	N	%
Racial/Ethnic Identity		
Non-minority	201	78.2
Minority	56	21.8
Family Higher Education History		
Not first-generation to obtain 4-year degree	196	76.3
First-generation to obtain 4-year degree	61	23.7
Community		
Urban	159	61.9
Rural	98	38.1
Gender		
Female	182	70.8
Male	72	28.0
Non-binary/Prefer not to respond	3	1.2
Classification		
Freshman	62	24.1
Sophomore	49	19.1
Junior	70	27.2
Senior	73	28.4
Graduate/Nontraditional	3	1.2
Major		
Animal Science	62	24.1
Dairy Science	33	12.8
Other[1]	162	63.0

[1]Other = primarily other (non-specified) majors in the College of Agriculture and Life Sciences based on historic course enrollment.

Table 9.3. Summary of categories and sub-categories of student educational experience in the community of inquiry (CoI) framework.

Category	Sub-Category
Social Presence	Affective expression Open communication Group cohesion
Cognitive Presence	Triggering event Exploration Integration Resolution
Teaching Presence	Design and organization Facilitation of discourse Direct instruction

Table 9.4. Instructors' (N = 10) reported accommodations and technologies during emergency remote teaching in the Spring 2020 semester.

Item	Freq.
<u>Training and supports for students during adaptation to remote learning</u>	
Grading policies were altered to account for the adjustment to online learning	6
Updated syllabus was posted	6
Students were provided online-learning help resources (e.g. help navigating online learning environment)	4
Students were surveyed about their connectivity needs, access to internet	3
Students were provided well-being resources (e.g. mental health support)	2
Offered that students should contact instructors with questions/feedback	2
None of the above / Not applicable	2
Switched from discussion mode to lecture mode	1
<u>Accommodation procedures during remote learning</u>	
Accommodations made for students with unanticipated technical difficulties (e.g. internet or computer crashing)	8
Accommodations made for students with no ability to video-conference (e.g. low internet speed)	7
Accommodations made on an as-needed basis for individual students (not announced to students or added to syllabus).	6
All new accommodations announced VERBALLY	5
All new accommodations added IN WRITING to syllabus or in course materials	4
Accommodations made for students with additional childcare/familycare responsibilities	3
None of the above / Not applicable	1
<u>Technologies used during remote learning</u>	
Canvas	9
BBCollaborate Ultra	8
Other / None of the options / Not applicable	2
Zoom	2
Instructor's own course website	2
Webex	1
Google Hangouts	1
Adobe Connect	0
Piazza	0

Table 9.5. Count of animal sciences instructors (sample n = 10) employing selected remote teaching methods during the Spring 2020 semester.

Item	Count
Students asked to read/view material for upcoming class session	8
Students read/view material on upcoming class session and complete assignments or quizzes on it shortly before class or at beginning of class	6
Reflective activity at end of class, e.g. "one-minute paper" or similar (students briefly answering questions, reflecting on lecture and/or their learning, etc.)	4
Student presentations (verbal or poster)	3
None of the above / Not applicable	1

Table 9.6. Frequency of instructors' (n = 6) use of selected technologies during video-conferenced synchronous classes.

Item	Never	A few classes	Nearly every class
Chat box	0	0	6
Google docs or other synchronous workspace	3	1	2
Polls	2	3	1
Breakout groups	3	2	1
Virtual whiteboard	2	3	1

Table 9.7. Count of instructors (n = 10) providing selected types of supporting materials during remote learning in the Spring 2020 semester.

Item	Count
Lecture notes or course PowerPoint presentations (partial/skeletal or complete)	9
Animations, video clips, or simulations related to course material	5
Other instructor-selected notes or supporting materials, pencasts, etc.	5
Articles from related academic literature	5
Grading rubrics for papers or large projects	5
Solutions to homework assignments	4
Student wikis or discussion boards with little or no contribution from you.	3
Student wikis or discussion boards with significant contribution from you or TA.	3
Worked examples (text, pencast, or other format)	3
Practice or previous year's exams	3
Examples of exemplary papers or projects	1
None of the above / Not applicable	0

Table 9.8. Structure of assignments and feedback to students provided by n = 10 animal sciences instructors during remote teaching in the Spring 2020 semester.

Item	Count
Assignments during remote teaching	
Homework/problem sets assigned and contributed to course grade at intervals of 2 weeks or less	7
Paper or project (an assignment taking longer than two weeks and involving some degree of student control in choice of topic or design)	4
Encouragement and facilitation for students to work collaboratively on their assignments	4
Group projects or assignments	3
None of the options / Not applicable	2
Homework/problem sets assigned or suggested but did not contribute to course grade	0
Feedback during remote teaching	
Students see graded midterms	8
Students see graded assignments	6
Students see assign. answer key	6
Assignments with feedback	5
Students see midterm exam quiz answer key	4
Students explicitly encouraged to meet individually with instructor	4
Online office hours offered	4
None of the above, Not applicable	0

Table 9.9. Count of animal sciences instructors (n = 10) employing select strategies to learn how to teach their course remotely in the Spring 2020 semester.

Item	Count
Discussed how to adapt elements of the course to online format with colleague(s)	7
Discussed online teaching practice with colleague(s)	7
Participated in additional training offered for instructors (e.g. training to use Canvas, BBCollaborate, other continuity of instruction resources).	6
Read literature about teaching and learning relevant to moving the course online	5
Used or adapted materials provided by colleague(s)	4
Read blogs, websites, or other informal resources relevant to moving the course online.	4
None of the options / Not applicable	1
Sat in on colleague's class (any class) to get/share ideas for teaching	0

Table 9.10. Student perceptions of educational experience based on community of inquiry framework subscales ranked according to means (N = 261 responses).

Subscale	Items	Category	α[1]	M	SD
Design & Organization	4	Teaching Presence	0.85	4.4	0.8
Resolution	3	Cognitive Presence	0.85	4.2	1.0
Direct Instruction	3	Teaching Presence	0.76	4.1	1.0
Facilitation	6	Teaching Presence	0.89	4.1	1.0
Integration	3	Cognitive Presence	0.82	4.0	1.0
Exploration	3	Cognitive Presence	0.78	3.8	1.1
Open Communication	3	Social Presence	0.83	3.8	1.1
Triggering Event	3	Cognitive Presence	0.89	3.7	1.2
Group Cohesion	3	Social Presence	0.82	3.6	1.1
Affective Expression	3	Social Presence	0.84	3.3	1.2

[1]Cronbach’s alpha coefficient for the subscale

Table 9.11. Linear mixed-effects models describing variance in Community of Inquiry scales attributable to student demographics and course.

	Social Presence		Cognitive Presence		Teaching Presence	
Predictors	Est.	*p*	Est.	*p*	Est.	*p*
(Intercept)	2.72	<.001	2.73	<.001	3.06	<.001
Non-major	0.10	.55	0.17	.25	0.08	.57
Non-male	-0.17	.15	0.07	.53	0.04	.69
First-generation	0.18	.16	0.03	.80	0.05	.61
Urban	0.09	.44	0.11	.33	0.05	.60
Minority	0.12	.35	0.01	.94	0.05	.65
Sophomore	-0.07	.66	0.08	.62	0.10	.46
Junior	-0.17	.34	0.01	.97	0.04	.79
Senior	-0.18	.30	0.15	.34	0.14	.35
Graduate/Non-traditional	0.65	.20	0.55	.25	0.24	.58
Random Effects[1]						
σ^2	0.67		0.58		0.49	
$\tau_{00\ course}$	0.19		0.12		0.10	
ICC_{course}	0.22		0.17		0.17	
N_{course}	8		8		8	
Observations	257		257		257	
Marginal R^2	0.05		0.03		0.01	
Conditional R^2	0.26		0.20		0.18	

[1]The σ^2 and τ_{00} represent the within-group and between-group variance, respectively. ICC_{course} shows the intraclass-correlation coefficient for the random effect of course.

Table 9.12. Linear mixed-effects regression describing student satisfaction with emergency remote learning from selected educational experience and demographic variables.

	Satisfaction with emergency remote learning		
Predictors	Estimates	95 % CI	*p*
(Intercept)	0.66	0.00 – 1.31	.05
Teaching Presence	0.23	-0.05 – 0.51	.10
Social Presence	0.37	0.18 – 0.55	<.001
Cognitive Presence	0.22	-0.06 – 0.50	.13
Non-major	0.13	-0.17 – 0.44	.39
Non-male	0.25	-0.01 – 0.52	.06
First-generation	-0.15	-0.42 – 0.13	.29
Urban	0.20	-0.07 – 0.46	.15
Minority	-0.18	-0.47 – 0.11	.22
Sophomore	-0.23	-0.59 – 0.13	.20
Junior	0.27	-0.09 – 0.64	.14
Senior	0.15	-0.21 – 0.50	.42
Graduate/Non-traditional	0.28	-0.83 – 1.40	.62
Random Effects[1]			
σ^2	0.85		
$\tau_{00\ course}$	0.02		
ICC_{course}	0.03		
N_{course}	8		
Observations	257		
Marginal R^2	0.32		
Conditional R^2	0.34		

[1]The σ^2 and τ_{00} represent the within-group and between-group variance, respectively. ICC_{course} shows the intraclass-correlation coefficient for the random effect of course.

Table 9.13. Generalized linear regression with logit link illustrating the relative risk of students reporting losing engagement during emergency remote learning for selected educational experience and demographic variables.

	Losing engagement during emergency remote learning[1]		
Predictors	Risk Ratio	CI	*p*
(Intercept)	1.7	1.4 - 1.9	<.001
Teaching Presence	0.7	0.4 – 1.0	.06
Social Presence	0.8	0.6 – 1.0	<.05
Cognitive Presence	1.1	0.8 - 1.4	.44
Non-major	1.1	0.8 - 1.4	.35
Non-male	0.9	0.7 - 1.2	.73
First-generation	1.2	0.9 - 1.5	.12
Urban	0.9	0.6 - 1.2	.50
Minority	0.8	0.5 - 1.1	.18
Sophomore	1.2	0.8 - 1.6	0.31
Junior	1.1	0.7 - 1.5	0.57
Senior	1.3	0.9 - 1.6	0.19
Graduate/Non-traditional	1.7	0.5 - 2.1	0.23
Observations	257		
Tjur's R^2	0.10		

[1] Risk ratios, 95% confidence intervals (CI), and p-values were calculated from the log-odds coefficients.

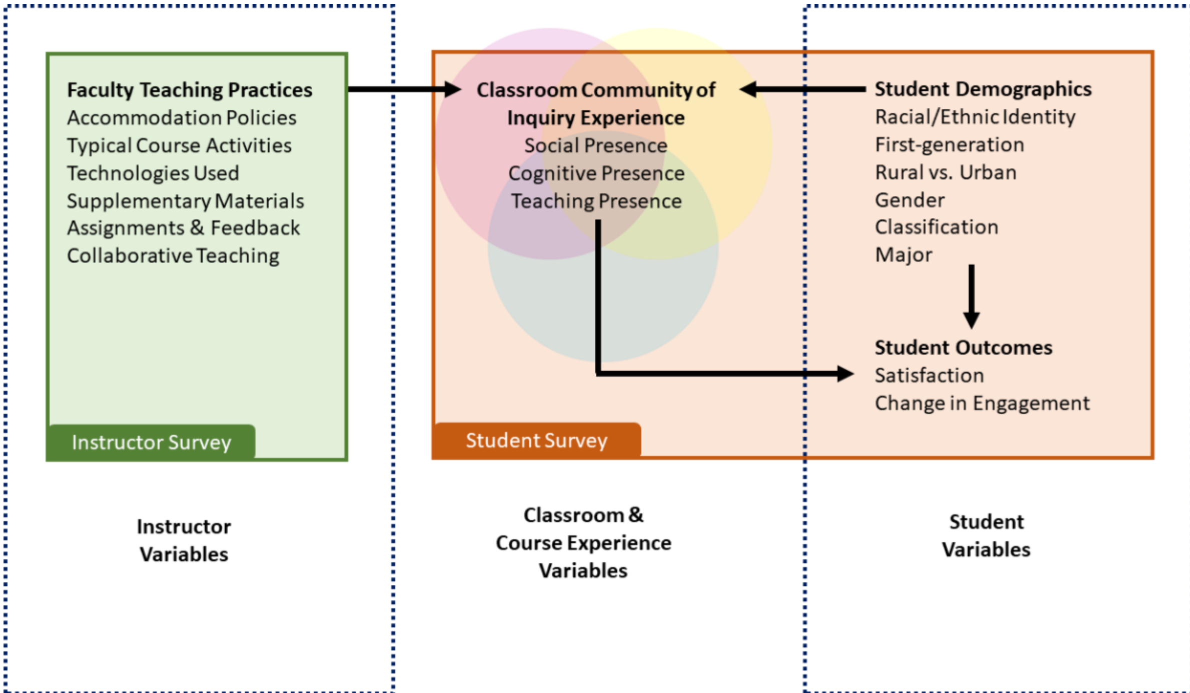

Figure 9.1. Conceptual model of instructor, course, and student variables assessed in this study.

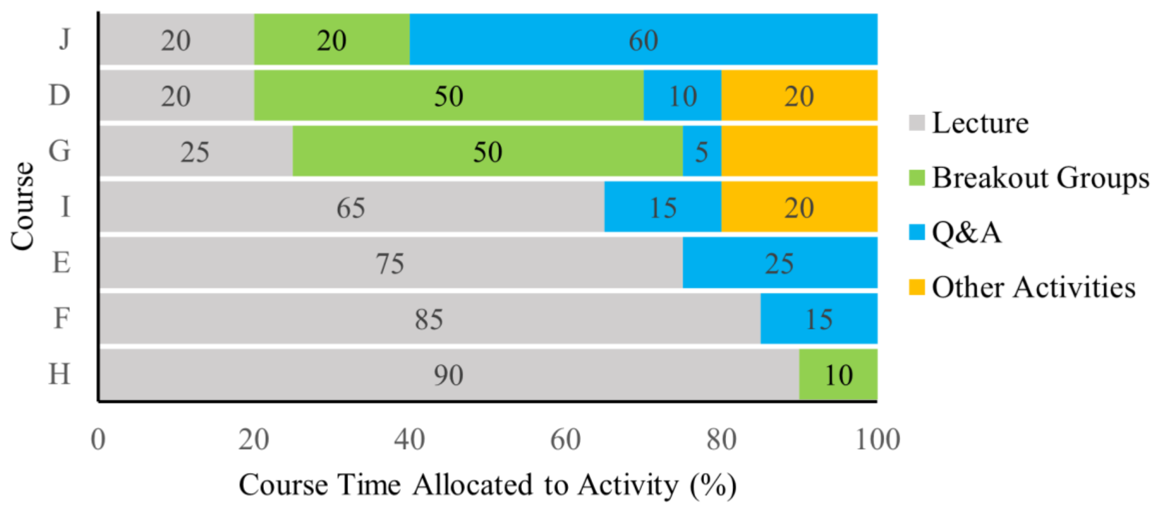

Figure 9.2. Allocation of video-conferenced session time to selected activities in courses with synchronous components (n = 6 instructors, 7 courses).

CHAPTER 10. CASE STUDY: INTRODUCTORY STUDENT ONBOARDING WITH A PLACE-BASED, BLENDED WELCOME TOUR

Citation:

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10.1 Abstract

Many introductory students face challenges adjusting to new geographic, social, and cultural contexts involved in their course of study, yet the extent of a student's integration and "sense of place" in an academic environment is associated with their performance and persistence toward related goals. This case study describes a place-based blended learning activity we created in ArcGIS StoryMaps (https://storymaps.arcgis.com/) to acclimatize students to the novel environment of an introductory animal sciences course during the first week of the semester. Using an embedded mixed-method design, this activity combines two complementary sources of data: 1) a qualitative personal account of activity design and implementation during the fall 2020 and fall 2021 semesters, and 2) an embedded quantitative survey of student learning outcomes and perceptions of the activity in the fall 2021 semester. Qualitative results illustrated instructional design choices related to the course context and instructional constraints and illuminated potential modifications to the activity's collaborative and assessment elements. Quantitative results on a 5-pt. anchored scale suggested that the activity was very effective at orienting students to the course's geographic context (M = 4.0, SD = 0.9), moderately effective at facilitating social bonding (M = 3.5, SD = 1.1), and moderately effective at increasing historical-cultural awareness related to the department (M = 3.2, SD = 1.3). Our results indicated that blended, place-based learning served as an effective onboarding activity in the context of our course.

Keywords: ArcGIS, StoryMap, place-based, blended learning, campus tour, introductory

10.2 Introduction

Post-secondary introductory courses serve as the initial gateways to participation in scientific and agricultural disciplines, where students' experiences can either promote their sustained engagement or instead incline them to drop-out (Scott et al., 2017; Parsons et al., 2002; Koenig et al., 2012). Research has shown that student experiences during the first week of a college class can impact their motivation and performance longitudinally. For example, Wilson and Wilson (2007) reported an experiment on the first day of an introductory psychology course, in which students randomly assigned a positive-emotional-tone overview lecture out-performed students assigned a neutral-emotional-tone overview and content lecture throughout the semester. Although experimental work is currently limited, classroom observation and survey research suggest that many first-week experiences in undergraduate introductory science, technology, engineering, and mathematics (STEM) courses may underutilize the motivation- and performance-boosting potential of the first week course sessions. For example, in direct observations of the first-day topics covered by STEM instructors participating in a faculty development program, Lane et al. (2021) found wide variation in the percentage of class time allocated to STEM content and non-content topics. On average, these instructors dedicated very little of the first class period to building community and promoting diversity and inclusion, instead focusing primarily on course policies and basic information (Lane et al., 2021). With respect to the format, Friedrich and colleagues (1993) found that most first-day experiences were lecture-based and did not employ interactive or collaborative strategies in a survey of 145 STEM and non-STEM instructors. These studies of introductory topics and format are consistent with the content-focused, lower-cognitive-level learning goals embodied at the course level by the learning goals and assessment items of 77 introductory STEM courses analyzed by Momsen et al. (2010). In summary, these results indicate that introductory STEM courses often use content- and policies-focused first week teaching practices that offer less support for the retention and performance of their diverse student constituents relative to student-centered learning (Freeman et al., 2014; Theobald et al., 2020).

Although not mainstream in introductory STEM courses, the literature is replete with instructional models that effectively support student performance and retention in various introductory settings. For example, authors have designed introductory STEM course activities that aim to develop students' skills for self-regulated learning, build their networks of learning resources, and socialize them to intellectual communities (Ryan & Glenn 2004; Tinto, 1993; McGinley and Jones, 2014). In recent years, growing acceptance of educational technology has vastly expanded options for coordinating student-centered learning in college classrooms, especially impacting large-enrollment courses (Lee, Morrone, & Siering, 2018). Digital technologies enable new forms of student-driven, active, collaborative learning not only in traditional, centralized classroom settings but also in distributed and distance education (Xiao, 2018). As the higher education system incorporates new technologies and adapts to changing student needs, few recent authors have re-examined how to craft early experiences in introductory courses that support student performance and retention (Lane et al., 2021). Because the characteristics of introductory STEM courses and their student populations vary tremendously across departments, institutions, and disciplines, the first-day or first-week experience is likely a highly-contextualized phenomenon requiring in-depth, multi-layered description.

10.2.1 Purpose and Research Questions

This case study describes a place-based blended learning activity called “UW--Madison Animal & Dairy Science: The Welcome Tour” we designed to assist learners in orienting themselves geographically, socially, and culturally as they begin a large-enrollment introductory course, while fitting the practical needs of our instructional team. Our research centered on one exploratory and one descriptive question:

1. What elements of the activity design and implementation did our students and instructional team perceive worked well, and what should be explored in future research?
2. To what extent did the activity accomplish its objectives to 1) orient students geographically to facilities used in labs, 2) facilitate social bonding, and 3) increase awareness of prominent cultural-historical themes in the Animal & Dairy Sciences Department?

10.3 Materials and Methods

10.3.1 Instructional Design Framework

Onboarding

In this case study, we borrow the organizational psychology term “onboarding” (e.g., Bauer & Erdogan, 2011) to describe instructional efforts that support learner integration into unfamiliar geographic, social, and/or cultural contexts as they begin a course of study. This positions onboarding as an early intervention in the longer-term project of supporting undergraduate performance and persistence (Kerby, 2015; Tinto, 1975). Onboarding activities may aim to support students in self-contextualization, for example, reflections designed to cohere autobiographical understanding and develop vocational identity (Habermas & Bluck, 2000). Onboarding may also aim at building self-regulated learning skills through practice and explicit instruction (Roberson, 2018), strengthening social ties and supporting social belonging (Turetsky et al., 2020), and connecting with on-campus or external learning and information resources (Hungerford et al., 2021). By altering students' experiences as they transition into a course of study, onboarding attempts to soften negative psychological responses to change and instead take advantage of the transformative learning potential of disorientation (Chow & Healey, 2008; Raikou, 2018). Research has shown that targeting student academic, social, and personal integration with onboarding activities has clear benefits on their motivation and performance throughout undergraduate study (Dika & D'Amico, 2016; Ryan & Glenn, 2007; Walton & Cohen, 2011). Evidence suggests that effectiveness of onboarding activities varies based on the types of activities and the learners' characteristics. For example, researchers have found that onboarding activities yielded larger positive effects on retention and performance for those in historically excluded groups and first-generation college students, compared with respective reference groups (Jamelske, 2009; Leary et al., 2021). Onboarding activities also drastically shaped the reported experiences of transfer students (Townsend & Wilson, 2006). This evidence indicates that in the context of introductory courses, which convene richly varied groups of novice learners, onboarding is critical not only to supporting the performance of individual students, but also to creating an equitable and inclusive social learning environment.

Place-based learning

The concept of onboarding lies at the intersection between an individual and their geographic, social, and cultural environments—in other words, their situatedness or “rootedness” within a place. Theories of humanistic geography contrast “spaces” which are objective and material locations, with “places,” which additionally include the socially constructed meanings ascribed to locations (Agnew, 2011; Ujang & Zakariya, 2015). Place is therefore enacted, embodied, and experienced by people in both individual and collaborative ways.

Although place-based learning has been discussed as an entry-point to teaching concepts across the curriculum and often conveys disciplinary content, instructors can leverage person-place interactions as the entry-point for transformative learning, i.e., learning that shapes individual and/or collective identities (Pisters et al., 2019; Sobel, 2004). Place experiences prompt affective, cognitive, and behavioral processes that influence the individual’s personal and social identities and goals (Steele, 1981). For example, strong attachments to place can crystallize into aspects of an individual’s identity where they become robust predictors of behavior (Bott et al., 2003). Shared place experiences can facilitate the formation of social bonds (Johnson et al., 2020). Place-based learning also has implications on learners’ integration with and transmutation of organizational cultures. Lim (2010) argued that place-based learning that affirms the multiplicity of place histories in a given context can support students’ intercultural skills and promote inclusivity. These findings suggest that learning centered on campus places can nudge behavioral and psychosocial processes affecting learners’ integration in their physical and social environment and their perceived “sense of place” (Kerby, 2015).

In introductory courses, virtually all students are transitioning to a new field of study, and many students (i.e., first-year and transfer students) may additionally be transitioning to university life (Chow & Healey, 2008). These conditions challenge the "sense of self-in-place" which can undermine the individual's psychological security and impede their integration into new learning environments (Cantrill & Senecah, 2001; Wang et al., 2019). Conversely, evidence suggests that place-based onboarding activities can promote introductory learners' psychological security and integration by grounding their identity and experience in a local socio-spatial context (Scannell & Gifford, 2017).

Blended learning

Following Garrison and Kanuka (2004), we defined blended learning as the combination of in-person experiences with internet-mediated learning. Whereas in-person learning requires the synchronous physical co-presence of a group of learners and their instructor, and whereas distance learning is entirely internet-mediated with no physical co-presence, blended learning is inclusive of a broader range of learning situations: synchronous or asynchronous, and physically-present or distance-learning (Oliver & Trigwell, 2005). Because this definition is so broad as to include nearly all forms of modern undergraduate instruction, researchers have emphasized the need for description of blended learning to detail the quality and quantity of blending between instructional modes and the level of operation (e.g., activity- versus course-specific blending; Hrastinski, 2019). Graham (2006) discusses qualitative differences in the ways instructors select elements of learning to occur via on-line versus in-person modes, and on the ways these elements coalesce in the learning environment. In contrast, many universities defined blended learning administratively based on the quantitative proportion of course time or course content occurring online in relation to in-person instruction (Allen & Seaman, 2010). As educational technology increasingly permeates higher education, the boundaries between in-person, blended, and fully-online learning have blurred (Dahlstrom & Bichsel, 2014; Martin et al., 2020). Recently, the COVID-19 pandemic accelerated instructor and institutional adoption of blended and online learning techniques (Lee & Jung, 2021). In the post-pandemic-onset world, blended learning activities may match the needs of both students and instructors more than fully-online or traditional in-person instruction (Erickson & Wattiaux, 2021). Blended instructional modes can complement place-based learning by promoting deeper, more autonomous, more collaborative engagement of students with places (Hagood & Price, 2016).

10.3.2 Context: Onboarding in Introduction to Animal Agriculture

For students embarking on an Animal & Dairy Science (AnDySci) trajectory, the agricultural campus at our land-grant university forms a rich landscape of practical opportunities in related coursework, extra-curricular activities, and employment. In addition to signifying future opportunities, the campus geographic context also serves as a window into the AnDySci department's historical significance. For example, locations on the agricultural campus can signify famous historical or modern scientific discoveries. Finally, places on campus can communicate the agricultural campus organizational culture by signifying its important norms, values, and symbols.

In contrast to the learning strategies and academic socialization models outlined by Ryan & Glenn (2004), our introductory course aligns with the discipline-based theme model of introductory course described by Porter and Swing (2002). The majority of course time is dedicated to previewing subspecialities that both represent options within the major at our institution and previewing areas of engagement in the broader disciplinary community. Students are predominantly first-year and predominantly pursuing AnDySci majors. The course meets three times weekly for one 50-min. lecture, and once weekly for a 3-hr laboratory. Our class size averages 90-100 (two laboratory sections of 40-50), which can pose logistical challenges for our small instructional team (one faculty associate and two to four graduate and undergraduate laboratory teaching assistants). In part to overcome logistical constraints, the instructional team historically allocated 20-50% of lab time to student-driven activities requiring minimal guidance from our instructional team.

Our instructional team perceived constraints including limited class time for non-content learning and a large student-instructor ratio. Additionally, we required the activity to accommodate both synchronous, in-person participants for the main course session as well as asynchronous and/or virtual participants. The proximal objectives of this activity were to 1) orient students geographically to facilities we would use in their introductory course labs, 2) facilitate the formation of social and professional relationships among small groups of classmates, and 3) build awareness of prominent cultural-historical themes in the department for students to understand and challenge.

10.3.3 Case Study Design

This single-case report describes the "UW—Madison Animal & Dairy Science: The Welcome Tour" activity as implemented in our AnDySci 101 course. Table 1 shows a timeline of major teaching and research events in the case study. We used an embedded mixed-method design with two complementary sources of data (Creswell, 2005). First, the first author's qualitative personal account as an instructor-designer documents the activity's design process and implementation in both the fall 2020 and fall 2021 semesters. Second, an embedded quantitative survey describes student learning outcomes and perceptions of the activity in the fall 2021 semester. Whereas the personal account is descriptive and inductive, the student survey is deductive. The co-analysis of these multiple, complementary data sources offsets potential weaknesses associated with each data collection method (Yin, 1994). Likewise, the choice of case study method allows for richer contextual description and accommodates greater complexity, making it suited to studying onboarding, which encompasses a wide range of instructional activities inextricable from the course, departmental, and institutional context.

10.3.4 Instructional Design Methods

To create the Welcome Tour StoryMap, the first author started by designing the tour on paper, selecting 12 important locations for students interested in animal science. For example, the tour included buildings such as campus animal facilities, the Vet School, a life sciences library, and the dairy and meat retail stores. Then, the locations were arranged into a logical order, such that students could safely walk on sidewalks and crosswalks and complete the tour as a large loop with minimal backtracking.

Then, the Welcome Tour was designed onto an ArcGIS StoryMap (https://storymaps.arcgis.com/). To generate a web map, we marked locations and set navigation boundaries on an open source “community basemap” available through ArcGIS. For the StoryMaps layout, we selected a side-by-side option (Figure 1). In this layout, a map of numbered destinations pans and zooms in response to scrolling in a sidebar. Conversely, the sidebar responds when a viewer clicks a destination on the map. The sidebar contained a vertical list of 12 descriptive boxes—one for each destination. Each descriptive box included 30-70 words summarizing the relevance of the location to current students and sharing historical “fun facts.” To be inclusive of all our students (including some with mobility restrictions or in quarantine), we optimized the Welcome Tour activity both for mobile devices as an in-person walking tour, and for personal computers as a fully-virtual activity. Our AnSci 101 Welcome Tour StoryMap is viewable here: https://arcg.is/1HK4uS

Our instructional team has used this activity in two recent years as a component of the first course laboratory. In Fall 2020 we tested this activity as an individual self-guided, self-paced activity due to COVID-19 restrictions with N = 80 students. We posted brief instructions and a link to the activity on our learning management system. To add collaborative and assessment elements, we invited students to submit a brief 1- to 2-minute video at a destination of choice introducing themselves and to comment on the videos of their peers (FlipGrid Inc., Minneapolis, MN). We awarded 3 pt. for completion, representing 0.2% of total pt. available in the course.

In Fall 2021, we offered the Welcome Tour activity as a peer-group-led activity during the final 1.5-hr of the first 3-hr synchronous in-person laboratory session of the semester with N = 94 students. During this lab, students chose their seats at round tables and we provided them adhesive nametags. After a 40- to 45-min. interactive lecture on policies and procedures for course laboratories, we assigned small groups (4-6 students) based on physical sections of tables. They then completed several ice-breaker activities (40-45 min.) in which they introduced themselves to group-mates, worked collaboratively on an open-ended creative project, and set goals for the course. Subsequently, we reconvened the entire class to explain the tour procedures (3-5-min.). Students accessed the tour by scanning a QR code projected on classroom display screens. We assigned each of the 12 groups to start at a tour destination corresponding to their group number. As an assessment, we offered students laboratory participation if one group member submitted an informal photo of their group at each of the 12 locations to a secure drive. With student consent, we added these photos to our class's shared photo album on our learning management system. We intended this low-stakes, low-input participation assessment to promote identification with and entitativity of social groups at the small group and full-class level.

10.3.5 Case Study Research Methods

Qualitative personal account procedures

The first author's personal account was based on observation and interpretation of events and records representing student and instructor participants in the Welcome Tour activity. Student sources included student behavior before and after the activity, student media submitted as the assessment, informal feedback from students during the semester, and formal feedback from students in the regular course evaluations at the end of the semester. Sources related to our instructional team included the first author's personal experience and feedback from regular debriefing with others on the instructional team. Due to the activity design, no one accompanied individual students (Fall 2020) or student groups (Fall 2021) around campus to directly observe their experience during the activity. To document qualitative data, the first author kept detailed notes on any phenomena judged as relating to the tour activity under the arbitrary headings of "design" and "implementation." Throughout the semester, the first author continually referred to her notes to add detail or personal reflections. Finally, in Spring 2022, the first author discussed her notes and reflections with the second author--an experienced undergraduate instructor--to determine the main findings.

Quantitative survey design and administration

We did not quantitatively assess the initial iteration of the Welcome Tour activity in Fall 2020. In Fall 2021, we administered a brief evaluation of the Welcome Tour activity's second iteration. The Institutional Review Board approved all study procedures. We created four total survey items: three items with anchored scales (5-pt. scale "not at all [1]" to "extremely [5]") based on the activity's three learning objectives, and a single multiple-choice item asking students if they believe the tour should be retained or dropped from the course (options: "I believe the Welcome Tour should be replaced with another activity;" "I believe the Welcome Tour should remain a part of Lab #1;" "I am neutral or unsure;" "Other [please explain below]"). We included these four items in the regular end-of-course evaluation administered online via Qualtrics (Qualtrics Inc., Provo, UT). Timing the survey at the end-of-semester (week 14) rather than immediately following the activity (week 1) was intended so that students would report their reflections on the activity effectiveness in light of their experience throughout the semester. On the final week of regular course sessions (week 14), the instructional team opened the survey and offered students two days to complete it individually outside of class. Our research team notified students they would be awarded 0.5% extra credit for survey completion and that their responses would be de-identified and not seen by instructors until after the semester ended to encourage their honesty (Shenton, 2004).

10.4 Results and Discussion

10.4.1 Instructor perspective and personal account

With respect to the design of the Welcome Tour content, we did not perceive a need to make substantial changes, though the cloud-based hosting and easy-to-use editor would make modifications straightforward. We found students effectively used the map to navigate around campus in both iterations of the activity. Although we have considered expanding the descriptive text for each location, the first author observed that students typically completed the tour using mobile devices. Additional descriptive text might be beneficial for a fully-virtual participant who does not visit campus locations. However, the first author's experience suggested that students completing the tour on-campus and in peer groups prefer concise text descriptions (<100 words) that do not detract from their experience of place and collaboration with peers.

Regarding implementation, we noticed several important considerations for our context. First, we felt the interactivity of the Welcome Tour effectively complemented the tedium of covering course policies in the first part of the lab session. Second, we found it important to maintain the order of activities: introductions, syllabus and course policies, then finally the Welcome Tour activity. By communicating critical course information early in the lab session, it avoided the need for a hard deadline for students to finish the tour activity. We believe this promoted deeper engagement and circumvented potential problems associated with coordinating the return of small groups to the classroom. Third, it occurred to us that weather conditions could threaten the efficacy of the tour activity if no contingency plans were made. So far, weather conditions have not obstructed students from completing the tour during lab hours. As a contingency, students could complete the activity on their own time (as in Fall 2020) or synchronously in small groups without leaving the classroom. Fourth, the first author noticed that the Welcome Tour facilitated more social bonding when offered in a peer-group-led synchronous format in Fall 2021 compared with the individual asynchronous format in Fall 2020. In addition to the format of the Welcome Tour itself, the observed differences in social bonding could also be related to the format of the preceding lab session. The Fall 2021 Welcome Tour was conducted following 1.5 hr. of synchronous *in-person* lecture and activities in the same peer group, whereas the Fall 2020 group followed 1.5 hr. of synchronous *emergency remote* lecture and activities. To improve the social dynamics, we have considered devising a method to intentionally design student small groups ahead of class or including more team-building elements the requirements for the activity. Finally, we took note of a few considerations related to the low-stakes assessments used. In Fall 2020, student submissions communicated enthusiasm about submitting videos to introduce themselves and document the tour. Likewise, in Fall 2021, we found student picture submissions were wonderfully expressive. In both iterations, >95% of enrollees completed these assignments. By design, this media submission assignment is a relatively relaxed assessment component intended to convey to students that they should focus on experiencing rather than performing. However, our instructional team has considered increasing the difficulty and complexity of the assignment with the goal of promoting positive interdependence of group members and setting high academic expectations for the semester.

10.4.2 Fall 2021 student survey

Table 2 shows student responses to the quantitative survey in Fall 2021. In total, 80 of 94 students completed the Welcome Tour evaluation survey (response rate: 85.1%). In anchored scale ratings assessing learning outcomes, students reported that the tour was “very helpful” to orienting themselves to the animal and dairy science buildings on campus (*M* = 4.0, *SD* = 0.9); “moderately” to “very” helpful to forming social and professional relationships with classmates (*M* = 3.5, *SD* = 1.1); and “moderately” helpful to gaining a sense for the Animal & Dairy Sciences department’s cultural and historical background (*M* = 3.2, *SD* = 1.3). Most students supported retaining the Welcome Tour activity in future years (n = 64; 80.0%), although a small fraction indicated they were neutral or unsure (n = 10; 12.5%) or “other” (n = 3; 3.8%), or that the Welcome Tour activity should be replaced with a different activity (n = 3; 3.8%).

In aggregate, these results indicated that the Welcome Tour activity met learning objectives and student expectations. Still, results suggested areas for future investigation and refinement related to students’ development of social and professional relationships in small groups and their cultural-historical learning. For example, future research could compare different group selection, composition, or facilitation strategies for this Welcome Tour or similar activities (Borges et al., 2009; Jensen & Lawson, 2011). Additionally, teacher-researchers could pilot test different versions of the activity to refine the descriptive text and facilitation components aimed at developing a sense of the department’s cultural and historical background while affirming multiple place-histories and cultural identities (Lim, 2010). Learners’ sense of belonging (or conversely, of alienation) may be a key outcome for further investigation as it is implicated in both social bonding and cultural-historical learning (Kaplan et al., 2020; Thomas, 2016).

10.4.3 Limitations & Extensions

Research Design

The credibility, transferability, dependability, and confirmability of the qualitative components of this case study rest upon a detailed account of context, instructional design methods, research methods, and positionality, as well as the use of complementary quantitative data (Creswell, 2005). The first author's close proximity to the phenomena under study allowed for the formation of a detailed contextual description, however, her personal account is inextricable from her positionality as the activity designer and facilitator during both semesters. Other participants were naturally aware of her involvement in activity design, facilitation, and course evaluation which may have biased certain qualitative data sources in this case study, especially informal feedback. Similarly, the first author's interpretation of the qualitative data stemmed from her involvement in scholarship of teaching and learning as a graduate teaching assistant and laboratory instructor. Future qualitative inquiries could incorporate student interviews and focus groups to characterize students' experience in greater detail. This additional data would allow triangulation, member checking, iterative questioning, negative case analysis, and other provisions to enhance qualitative trustworthiness.

Similarly, the quantitative results of this case study have important limitations in credibility, transferability, dependability, and confirmability. History and maturation effects may have affected the case study results because the case study examined a single group of students, i.e., the Welcome Tour was not compared to other different onboarding approaches. Additionally, although $<5\%$ of students dropped the course after the first lab, the quantitative survey includes results only from students who completed the entire semester course.

Additionally, measurement reliability and validity could not be assessed due to the use of single-item measures. Finally, participants in the quantitative survey were assessed at a single timepoint. Whereas cross-sectional assessments have been suggested to avoid response shift bias and compounding measurement error from two or more separate assessments (Little et al., 2019), single-timepoint data represent a brief window into participants' experience that may not be representative of their longitudinal outcomes. Future studies could assess students at more time points during the semester, develop valid measures of activity-specific student outcomes, adapt established measures of psychosocial adjustment outcomes, and/or use institutional data sources to track performance and retention longitudinally.

Instructional Design

Although ArcGIS StoryMaps has many possible extensions, the Welcome Tour described here is limited by our instructional team's particular objectives and context. First, the first author designed the Welcome Tour activity for first-year students with little campus familiarity. Other adaptations of the activity could consider the unique needs of more experienced students, who may prefer opportunities for individual learning and have a greater comfort level navigating campus. Second, our desired destinations spanned 12 locations across several city blocks of campus. When important destinations are constrained to a smaller geographic region, e.g., a single building, an ArcGIS StoryMap is less likely to be helpful. It may be possible to overcome this challenge by creating a custom basemap, however, open-source community basemaps are typically two-dimensional and detail the regional geography with building outlines, and no description of building interiors. Finally, our institutional license for ArcGIS allowed free access to the StoryMaps platform. For instructors who lack institutional access, it is possible to purchase an individual license for ArcGIS StoryMaps (https://www.esri.com/en-us/arcgis/products/arcgis-storymaps/buy, retrieved 2021.09.14). If StoryMaps is not available, Google Earth Creation Tools is an open-source alternative that supports creating map-based narratives, though with fewer features (https://www.blog.google/products/earth/new-google-earth-creation-tools/, retrieved 2021.09.14).

Aside from a campus-located Welcome Tour, there are numerous ways to use ArcGIS StoryMaps in agriculture teaching. Rather than campus locations, instructors could use global locations. StoryMaps can be built around complex basemap layers of topography, satellite imagery, administrative boundaries, and other natural and human-made features. Using the StoryMaps layout options, instructors can pair any type of map with various media, slideshows, and interactive elements. Beyond StoryMaps, technically-savvy instructors could use location-based augmented reality to build even more-immersive experiences. More practical instructors could blend StoryMaps with physical objects (e.g., hidden envelopes or prizes) to create a discovery journey. Our Welcome Tour represents a simple, easy-to-enact use case within the context of post-secondary agriculture; however, the StoryMaps website contains hundreds of examples illustrating additional possibilities.

10.5 Conclusions

Overall, end-of-semester survey results indicated that the place-based blended Welcome Tour tested in this research accomplished three important introductory course learning outcomes: 1) it helped students locate important campus facilities, 2) it facilitated the development of peer-to-peer social and professional relationships, and 3) to some extent, it introduced students to AnDySci department's cultural heritage. Future longitudinal research is needed to fully-understand the theorized distal impacts of this and similar place-based blended learning experiences on first-year students' academic performance and retention. These results showed that instructors can use ArcGIS StoryMaps and similar platforms to mediate place-based blended activities for introductory student onboarding.

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10.8 Tables and Figure

Table 10.1. Timeline of teaching and research activities related to the Welcome Tour activity.

Term	Teaching Events	Research Events
Summer 2020	• Designed and tested the Welcome Tour within instructional team.	• Recorded design process and considerations.
Fall 2020	• Students (N = 80) offered the Welcome Tour as an individual self-guided asynchronous activity due to ongoing COVID-19 restrictions. • Students submitted videos at a destination of their choice introducing themselves to peers.	• Collected qualitative data throughout the semester. • Instructional team discussed findings.
Summer 2021	• Updated the Welcome Tour instructions to accommodate for in-person, synchronous instruction. • No changes made to the tour destinations or map.	• Made notes justifying activity design changes.
Fall 2021	• Students (N = 94) offered the Welcome Tour as a peer-group-led activity during the final 1.5 hr of the first synchronous 3-hr in-person laboratory session of the semester. • Following ice-breaker activities, students completed the tour and submitted group photos at each location to a secure drive.	• Collected qualitative data during the semester. • Administered quantitative survey at the end of the semester. • Instructional team discussed findings.
Spring 2022	• None.	• First and second author discussed the aggregated qualitative and quantitative results as a research team to decipher main findings.

Table 10.2. Perceptions of Fall 2020 introductory animal sciences students (N = 80, response rate = 85.1%) on a place-based, blended laboratory activity titled the "Welcome Tour."

Item	Response Summary
To what extent was the Welcome Tour helpful to:[1]	Mean (SD)
Orienting yourself to the animal and dairy science buildings on campus	4.0 (0.9)
Forming social and professional relationships with your classmates	3.5 (1.1)
Gaining a sense for the Animal & Dairy Sciences department's cultural and historical background	3.2 (1.3)
Do you believe the Welcome Tour should continue in future years?	Count (%)
Should be retained in future years	64 (80.0)
Neutral/unsure	10 (12.5)
Other	3 (3.8)
Should be replaced with a different activity	3 (3.8)

[1]5-pt. anchored scale "not at all [1]" to "extremely [5]")

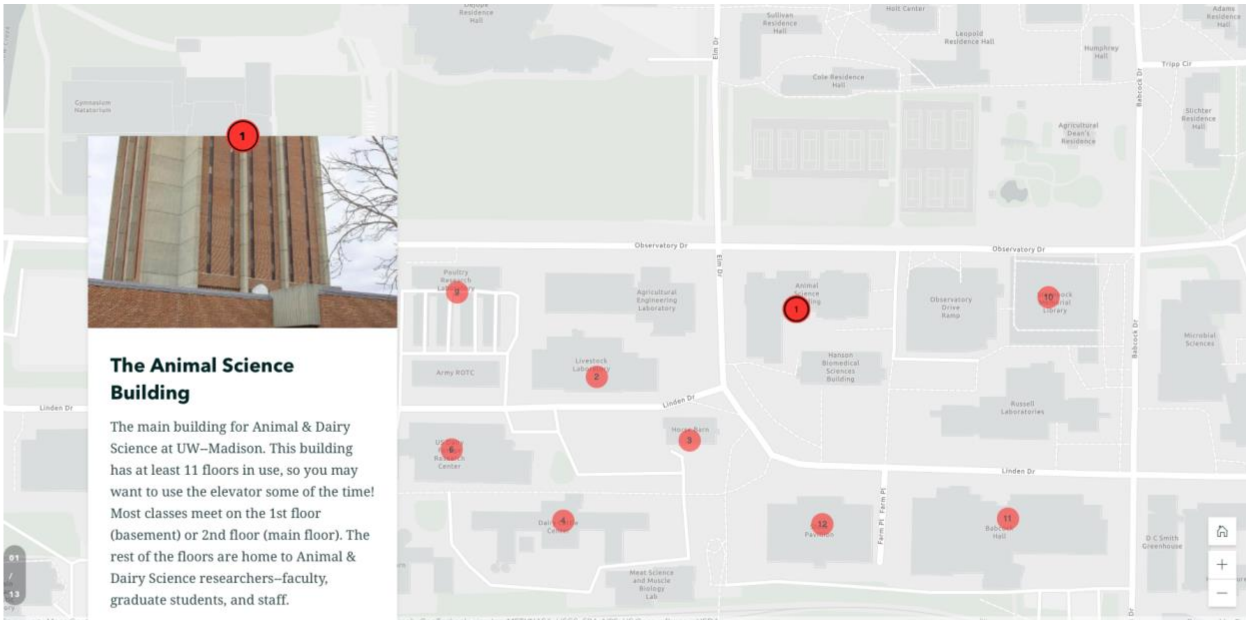

Figure 10.1. Side-by-side layout showing a description box for a tour destination and the basemap with additional numbered destinations.

CHAPTER 11. DIRECTIONS FOR FUTURE ANIMAL AND DAIRY SCIENCE EDUCATION RESEARCH

11.1 Abstract

To summarize the recent literature on animal and dairy sciences education, Chapter 6 (Erickson et al., 2020) reviewed n = 71 publications from 2008 to 2020. Consistent with the historical precedent discussed in Chapter 5, this scoping review revealed that discipline-specific content learning and core experiential learning remained central to animal and dairy science teaching and learning. The present Chapter synthesizes the historical and recent perspectives discussed in Chapters 5 and 6 with the subsequent Chapters 7, 8, 9, and 10 to suggest directions for future animal and dairy sciences research.

11.2 Literature Review

11.2.1 Building on strengths

One benefit of the preponderance of descriptive research in animal and dairy science is that demographics are robustly reported in a majority of studies. In addition to basic demographic information such as gender, race/ethnicity, rural/urban residence, classification, transfer status, age, and employment (hrs per week), many studies collect animal and dairy science specific information. For example, Albert (2012) reported the previous experiences of students with specific species. Similarly, Bundy et al. (2019) reported students' prior livestock experience and comfort level with individual species. Detailed demographics are available for studies throughout the past century (Taylor & Kauffman, 1983). However, some studies imply a deficit-based interpretation of the trend for declining average prior livestock experience (e.g., Bundy et al., 2019), which exemplifies the tension between traditional teaching practices and changing student demographics in animal and dairy sciences. Additionally, few studies change teaching practices or test multiple practices to improve their suitability to different student characteristics. Creating and testing teaching practices that support more inclusive, culturally-relevant learning environments represents a significant need for future research.

Course performance is the most-frequently documented outcome in the animal and dairy sciences education literature. For example, final course grades or quiz grades are used as an outcome variable in many studies (Bing et al., 2011; Vinyard et al., 2022; Moore, 2016; Southworth, 2014; Pratt-Phillips et al., 2010; Stutts et al., 2013; Soberon, 2012; Peffer, 2010; Burk et al., 2013). Although course grades ideally provide information about the relative fit of a student's work with teacher expectations, this approach is not without problems. First, course grades are often treated as a continuous, normally-distributed outcome although they are most often bounded from 0 to 100 and skewed. Second, course grades are presumed as a perfect metric of the underlying student ability at the task, although few researchers establish construct and scale validity or test measurement invariance across time or student populations (Kaplan, 2009). Third, grades may reflect biases of the teacher and teaching assistants. Fourth, grades are subject to testing effects that may also differ across students. Finally, course grades (especially when only a single final grade is presented) do not provide information about which aspects of the course can be targeted for improvement. Indeed, Lyvers-Peffer and Davis (2018) showed that animal and dairy science students' judgements of test performance were miscalibrated relative to instructors' and were subject to testing effects related to feedback and task order. In other STEM and life science disciplines, developing standardized concept inventories has established shared metrics for evaluating student performance on core concepts (Furrow & Hsu, 2019). Such standardized tests may provide benefits over informal tests in supporting student learning and enabling pedagogical improvement. In the spirit of "assessment for learning," standardized concept inventories may also help teachers diagnose specific conceptual hurdles and identify topic areas where their teaching can be improved (William, 2011). In lieu of standardized content knowledge tests, researchers could provide more detail or include major assessment items (tests, quizzes, final exams) in their reporting of results.

Although content learning is strongly prioritized by animal and dairy sciences instructors, outcomes related to students' interest and engagement arguably provide a more holistic view of the educational experience. For example, Peffer (2016) examined undergraduates' self-efficacy, intrinsic and extrinsic motivation, and positive and negative affect related to their animal science coursework. This author described reduced self-efficacy for transfer students and students working >25 hours pers week, which may present opportunities for teachers and administrators to provide additional support and flexibility for these students. Erickson et al. (2021) showed that utility-value-enhancing reflections improved the situational interest of students with low pretest individual interest but had no effect on the situational interest of other students. Authors have also measured motivation and engagement with specific course activities. For example, students in Hazel et al. (2013) reported cognitive engagement in team-based learning. Introductory students in Erickson et al. (2020) rated hands-on, problem-based laboratory stations as more challenging, novel, and attention-grabbing than case studies or video lectures. Haag et al. (2018) showed that students rated a beef cattle breeding simulation as more motivating and engaging compared with traditional homework assignments. These studies illustrate how animal and dairy sciences instructors assessed and compared different instructional formats and related them to student characteristics to optimize instruction. Still, compared with other STEM disciplines, there appears to be opportunities to make use of non-self-report measures of behavioral engagement such as classroom observation and assessment of learning artifacts (Smith et al., 2013). Validating animal-science-teaching-specific observational protocols and survey instruments seems to be an opportunity for future research.

11.2.2 Addressing methodological limitations

The literature suggests that animal and dairy science instructors often engage in teaching research without appropriate attention to methodological validity. This may stem from the ontological-epistemic belief set that 1) teaching and learning is inherently subjective and 2) subjective phenomena cannot be rigorously described or experimented with. For example, Taylor and Kauffman (1983) remarked on the results of a national survey of animal and dairy science instructors:

> *We are clearly dealing with a subjective, relatively intangible topic and yet a small minority still believes teaching can be measured objectively. They have been bold enough as to proceed to describe how it can be accomplished. (p. 177)*

In the animal and dairy science education literature, this is reflected in methods that are invented arbitrarily, poorly-justified, and poorly-documented.

First, most animal and dairy science education publications lack an explicit theoretical and/or conceptual framework. This limits cumulative knowledge-building because researchers operationalize new constructs that do not build on prior findings. The lack of theory also promotes surface-level description that fails to trace relevant mechanisms connecting participant characteristics, educational practices and experiences, and outcomes. When sensible, researchers could make use of theories and instrumentation developed in educational and cognitive psychology, or related fields such as biology education. For content-general constructs such as interest, motivation, engagement, intercultural competence, and even scientific literacy, externally-developed theories and instruments may produce more valid and informative results. However, there is clearly a need to develop animal and dairy science specific theories to describe phenomena specific to our discipline. This requires inductive research. Although inductive studies may not have a priori hypotheses based on established theory, they arguably require even greater detail surrounding the philosophical paradigms, assumptions, goals, research questions, and procedures used for the research compared with deductive research (Creswell, 2015).

Second, the animal and dairy science education literature is comprised mostly of quantitative observational studies, and there is tremendous opportunity to incorporate more mixed-methods, qualitative, and experimental designs (Shadish et al., 2002). Incorporating a greater variety of research designs not only has potential to expand the types of information accessible to researchers, but also to improve the validity of inferences. For example, collecting multi-source (instructor and student) and multi-method (qualitative and quantitative) data enables researchers to compare results between sources and methods. Using strategies such as triangulation and negative case analysis have the potential to improve the level of detail and validity of conclusions (Shenton, 2004).

A third area to improve animal and dairy science education research is attention to measurement validity. In education research more broadly, it is common to use survey instruments with multiple items per construct. The use of multiple items enables researchers to estimate parameters related to the underlying latent construct. Additionally, multi-item instruments enable researchers to explore and confirm that expected relationships between latent constructs are reproduced in the observed item-level variances and covariances (Kaplan, 2009). At most, animal and dairy sciences publications (from 2008 to 2020; Erickson et al., 2020) used multi-item instruments and reported Cronbach's alpha as an indication of internal consistency (McNeish, 2018). Other publications used single-item measures or did not examine internal consistency. Very few researchers used quantitative methods such as exploratory or confirmatory factor analysis or structural equation modeling. Considering the myriad quantitative and qualitative methods available for this purpose, it is imperative that future research place more emphasis on measurement validity.

Finally, and perhaps most importantly, the existing animal and dairy sciences teaching literature is limited by its focus on non-specific, nomothetic research questions. Recent authors have made small steps to account for individual-level and course-level factors affecting student outcomes. For example, Arnold et al. (2018) and Vinyard et al. (2022) recently asked whether course format (online versus in-person) affected student performance. These studies included some basic consideration of individual factors such as gender and contextual factors such as teaching assistant, semester, and institution. As Bernstein (2018) argues, education research that considers whether or not a pedagogy "works" asks an impractically broad question. Instead, to paraphrase, Bernstein suggests that educational researchers should ask…*which pedagogies result in substantively meaningful benefits when delivered by whom in what manner to what students with what characteristics and how durable are the benefits*. Bernstein's (2018) long-winded suggestion signifies a need for more detailed description of teaching practices, instructional contexts, participant characteristics, and outcomes associated with educational inquiries. As a practical example, the COVID-19 pandemic recently expanded institutional support for online and hybrid learning, while simultaneously changing student expectations in ways that differed across courses within a department (Erickson & Wattiaux, 2021). Because teaching practices were differentially affected by the pandemic in different courses, departments, institutions, and fields of study, a great deal more research is needed to characterize post-pandemic teaching and learning for various contexts and aims.

11.3 Conclusions

Animal and dairy science postsecondary educators create a space for stakeholders to confront the dairy industry's past and to construct its future. Amidst changing needs of students, employers, and the public as well as changes in the higher education system more broadly, we need education research to generate information that can guide decision-making. Using principles from other disciplines such as educational psychology and biology education, animal and dairy science postsecondary educators can contribute to building a cumulative evidence base that informs and energizes curricular and pedagogical change.

11.4 References

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