TRADITIONAL AND NON-TRADITIONAL STRATEGIES TO INCREASE STUDENT ENGAGEMENT AND MOTIVATION IN ANIMAL SCIENCE EDUCATION

A Dissertation

by

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ABSTRACT

Animal science educators face the unique challenge of engaging students in topics that can be scientifically rigorous, difficult for students to relate to their daily lives, and plagued with misconceptions. Three educational interventions are described herein which serve to promote engagement, motivation, and identity development among animal science students. These projects were grounded in experiential learning theory, constructionist and constructivist theories of teaching and learning, and theories of visual and verbal model-based reasoning. Studies were undertaken in a food microbiology course, a nutritional physiology course, and an industry connections minimester course. Students in animal science identify lack of hands-on experience as a challenge to their educational success. By participating in an experiential learning minimester course where they received firsthand experience in the livestock industry, students gained a broader vision of available careers, greater motivation to pursue their career goals, and a desire to share what they have learned with others. Similar courses could generate similar successes in motivating and preparing students to enter the livestock production industry. Drawing to learn in nutritional physiology deepened understanding and generated confidence among students in their ability to explain complex nutritional concepts and make comparisons among species. This activity was made more effective with the inclusion of a writing component asking students to combine both visual and verbal cognitive processes to increase comprehension. Similar combinations of visual and verbal modeling of complex physiological processes would likely be useful in other biological disciplines. Finally, incorporation of a student created

digital reference in food microbiology following constructionist and constructivist design principles contributed to development of a science identity among students as they engaged cognitively and emotionally with course material. Students also cultivated their self-efficacy and perceived agency, promoting development of identity as scientists. As learning can be defined as construction of knowledge leading to “becoming”, identity development is an important component of learning in STEM disciplines. Educators who choose to implement similar projects should consider that constructionist learning principles must be combined with elements of social constructivism to adequately scaffold learning and collaboration among students to glean the greatest results from the learning activity.

DEDICATION

I wish to dedicate this work to my two grandfathers Joseph Scaletti and Raymond Romatowski who instilled in me a love for learning and a deep appreciation for the value of education. I hope I have made you proud.

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CHAPTER I

INTRODUCTION AND REVIEW OF THE LITERATURE

Engagement

Student engagement in higher education is universally recognized as a predictor of student learning and outcomes. Despite the widely acknowledged importance of this topic, definitions of engagement remain nebulous, creating challenges in measuring student engagement at the class or institutional level (Handelsman et al., 2005; Kahu, 2013; Sinatra et al., 2015). A national survey of student engagement (NSSE) was developed in 2000 to attempt to identify and classify the quality of education through measures of engagement in learning practices known to promote deeper understanding, personal development, student retention, and completion of degree programs at 4-year institutions. Benchmarks established by the NSSE include academic challenge, student-faculty interaction, active and collaborative learning, enriching educational experiences, and a supportive learning environment (Kuh, 2003). A successor to the NSSE, the Australasian Survey of Student Engagement (AUSSE) added an additional benchmark of work-integrated learning along with the inclusion of outcome measures: higher-order thinking, accomplishment of learning outcomes, career readiness, grade, intentions, and satisfaction at the time of graduation or completion of a class. These surveys have been widely applied as a measure of educational quality across North America and Australasia although some refute the efficacy of their measurements.

According to Kahu (2013) benchmarks established by the NSSE are increasingly considered definitions for student engagement. Kahu argues that these student engagement surveys are primarily behavioral and fail to consider the emotionality of learning and intrinsic factors that promote student engagement and success. A more holistic approach to engagement would take into account a sense of belonging, individual investment in learning, and a conceptualization of learning as becoming rather than achieving (Newmann, 1992; Bryson and Hand, 2007; Kahu, 2013). While student engagement surveys do not take these cognitive and emotional factors into account, I would argue that the benchmarks of engagement outlined by the NSSE and the AUSSE could be applied at the classroom level to promote rather than assess student engagement.

Student conceptualizations of learning greatly affect their motivation to engage with course material. According to Handelsman et al. (2005), students who hold an entity theory of learning would describe themselves as having a specific capacity to learn that may at some point be reached. This idea of a set capacity for learning decreases engagement with difficult subjects as students are less likely to persist when encountering challenges. Conversely, students who hold an incremental theory of learning believe that their capacity for learning can grow and develop, and as a result will be more engaged in classes. For these students, engagement is viewed as a tool to increase their learning capacity.

Student goals will also determine their engagement. Students who view learning as a tool to increase competence and achieve their goals are generally intrinsically motivated and will be more resilient when faced with challenges. Conversely, students who set specific performance goals rely on the feedback of others for validation. These students are extrinsically motivated and will be more likely to disengage when encountering setbacks (Dweck and Leggett, 1988; Dweck, 1999; Handelsman et al., 2005; Dweck and Molden, 2017).

Student engagement in a course leads to increased motivation and effort in scholastic pursuits, creates a sense of belonging, and can generate conceptual change leading to deeper understanding (Kahu, 2013; Sinatra et al., 2015). Engagement is also linked to persistence within a major, especially those in STEM, and future career choices (Sinatra et al., 2015). To address disparities in conceptualization of engagement, specifically in STEM courses, Sinatra et al. (2015) separated the concept of engagement into 4 distinct categories: behavioral, emotional, cognitive, and agentic. Behavioral engagement is the most commonly applied definition of engagement and can be defined as participation in a course or learning activity. Current assessments of student engagement in higher education focus almost exclusively on behavioral engagement, a weakness in their reliability according to detractors of such assessments (Kahu, 2013). Behavioral engagement is important but on its own is insufficient to bring about conceptual change (Sinatra et al., 2015). Emotion is intrinsically linked to learning, a process involving not only generation of new knowledge and skills, but formation of a new identity. This is especially true of university students who are experiencing a new environment and community and are actively constructing an identity within their learning situation (Christie et al., 2008). Emotional engagement is achieved when the student finds some personal connection or value in the material they are learning which can be incorporated into their identity as a learner and is closely linked with intrinsic motivation. This incorporation leads to cognitive engagement where psychological effort must be expended, a struggle with current conceptualizations occurs, and students begin to integrate emerging concepts within their personal knowledge framework. Lastly, a sense of agency whereby students achieve a feeling of ownership and degree of proactivity, and potentially contribute to instruction, leads to agentic engagement (Sinatra et al., 2015). That is, students must participate in an activity, find some connection or personal value in what they are learning, expend effort and reflect on their learning, and achieve a sense of ownership of the material, potentially contributing to the flow of instruction through inquiry, discussion, or presentation. By addressing each of these elements of engagement, motivation and effort will increase, a sense of belonging will be developed, and conceptual change can be generated more readily. These 4 categories of engagement work together to promote learning as students participate, make connections, wrestle with cognitive dissonance, and personalize their knowledge. Due to the intersectionality of behavioral, emotional, cognitive, and agentic engagement, Sinatra et al. (2015) suggests that researchers describe engagement along a continuum with individuals at one extreme and the community or cultural context at the other. Researchers should describe the specific perception of engagement selected for study and acknowledge the existence of overlap between other aspects of engagement, along with grain size and measurement approaches. Conceptualization of engagement along the continuum described will allow more accurate comparisons between studies and selection of appropriate and comparable measurement approaches in future studies.

Identity and Motivation

A conceptualization of learning as “becoming” relies on the development of a learner’s identity, a complex and dynamic process. Development of identity occurs due to both external and internal influences, such as social dynamics, context, goals, and self-perceptions (Kaplan and Garner, 2017). Due to its complexity, the study of identity development has been inconclusive, as no simple linear approach is sufficient to accurately describe the manner in which identity is formed (Schwartz et al., 2011). Kaplan and Garner (2017) argue that identity can best be described as a complex dynamic system in which elements are correlative and interdependent so alterations to one element resonate through the entire system. As such, identity must be studied as a complete system, rather than by breaking it down into component parts. Identity is in a constant state of flux, as elements of the system change, rearrange, and integrate, generating new behaviors.

Kaplan and Garner (2017) proposed a theoretical framework by which to study identity development, the dynamic systems model of role identity (DSMRI). This framework integrates psychological, social, and cultural perspectives of identity formation within a specific role to understand the multifaceted nature of identity development (Figure I.1). The DSMRI framework can provide a starting point for researchers to describe the components of identity formation and how they may fit together in a complete whole. Additionally, the DSMRI framework provides a common language and approach with which to study identity development and allows for integration of studies examining disparate aspects of identity development.

According to the self-categorization theory, identity can most simply be defined as the manner in which a person defines themselves individually or as part of a group (Turner et al., 2012). Identity strongly affects learners' perceptions of their own capabilities and shapes potential actions taken in pursuit of their goals (Oyserman et al., 2006). Particularly within the context of STEM, identity is strongly linked to persistence and success within a major or career path, especially among underrepresented student populations (National Research Council et al., 2005; Olson and Riordan, 2012; Skinner et al., 2017). Learners with a strong science identity feel a deep sense of belonging in the scientific community, sharing their principles and goals. Additionally, these learners see the value in science as a career path, or its potential to solve societal issues (Skinner et

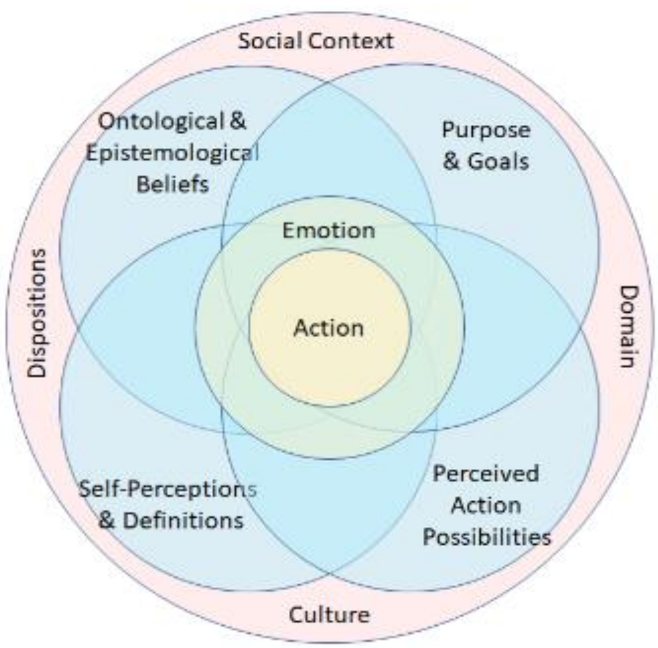


Figure I.1 The Dynamic Systems Model of Role Identity. Reprinted with permission from Choi and Donaldson (2020).

al., 2017). Development of a strong science identity provides a motivational foundation that is not easily rocked by obstacles or failures, allowing students to persevere through academic and personal challenges. To develop their identity as scientists, learners must be engaged behaviorally through academic work, and engaged emotionally, able to see the purpose and value in what they are learning and the way in which it connects to their lives or goals. Learners must also be engaged cognitively, being challenged, and proving their competency to themselves. Finally, learners must be engaged agentically, taking ownership of their own work and learning (Sinatra et al., 2015; Skinner et al., 2017).

To truly affect conceptual change, instructors must understand that motivation and engagement are part of the learning process itself (Hanrahan, 2002). Conceptual change does not come about through absorption of information but rather through the students' choice to value the information being taught, and to mobilize previous knowledge on which to scaffold and integrate new knowledge (Hanrahan, 2002; Velayutham et al., 2011). For new knowledge to be retained and applied, students must scaffold that knowledge on a previously existing knowledge framework. Each student will construct knowledge based on personal reference points. New information will either be assimilated into existing knowledge frameworks, used to further understanding, or it will be used to evaluate and adjust existing knowledge frameworks to accommodate new understandings. If there is no connection to their existing knowledge frameworks, students struggle to see the importance in what they are learning. Without tying new knowledge into previous experiences or real-world examples, students will default to memorization without meaningful application. Additionally, without connection to previous courses or experiences, students will struggle to apply knowledge in new contexts and will quickly forget what they are learning (Chaplin and Manske, 2005).

Motivation is a complex concept that can best be defined as the internal factor which instigates and focuses behavior in pursuit of a goal (Schunk, 2004). Motivation to learn is one of the strongest predictors of success and persistence in science (Velayutham et al., 2011). Engagement, identity, community, and self-perceptions collectively influence motivation and learning outcomes as demonstrated in Figure I.2. The following sections describe learning theory and practical approaches to promote engagement and motivation in higher education. Identity, engagement, and motivation

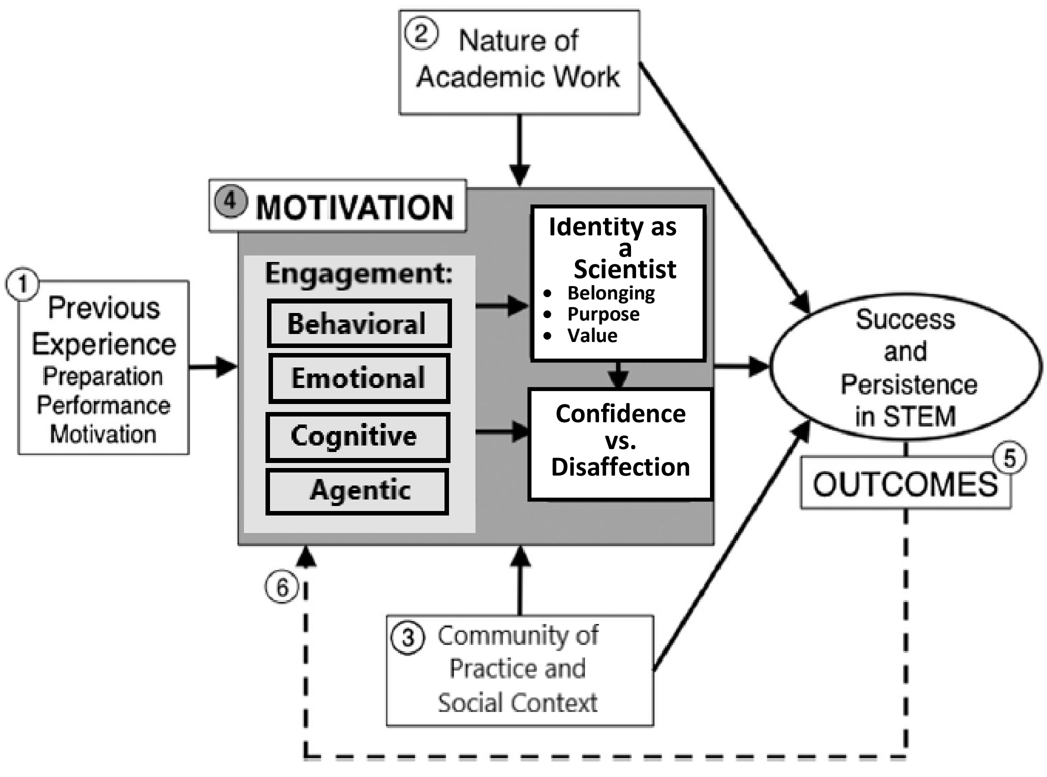


Figure I.2 Motivation and Identity, adapted from Skinner et al. (2017) and Sinatra et al. (2015).

are strongly linked and intercorrelated as each is dependent on the others. Therefore, learning design or interventions which promote one will invariably affect the other two. These strong associations may be leveraged by the educator as they develop innovative learning experiences.

Constructionism and Constructivism

Personal conceptualizations of learning heavily influence learning practices and outcomes (Donaldson, 2018). In a traditional setting, learning is often viewed as a transaction whereby an expert delivers information and the learner acquires it so learning is therefore the accumulation of information, similar to writing on a blank slate (Papert and Harel, 1991). This conception of learning has been termed instructionism, and is the basis for the development of common pedagogical strategies like lecture, drill and practice, and traditional exams (Papert and Harel, 1991; Donaldson, 2018; Donaldson, 2020). However, if the goal of learning is cognitive development of the learner and deeper understanding of the subject matter, instructionist practices are insufficient to meet the needs of the learner (Fosnot and Perry, 1996). An alternative conceptualization defines learning as the construction of knowledge, whereby learners actively create meaning from information, prior knowledge, and context of learning (Dunlap and Grabinger, 1996; Brown and King, 2000; Narayan et al., 2013). Under this definition, learning is an active and generative process where meaning is individualized and dependent upon each learners experience and understanding (Narayan et al., 2013).

Constructivist and constructionist learning theories are based upon the early work of Piaget and Cook (1952) in cognitive development. Piaget (1977) and (Vygotsky, 1980) described learning as a continuously constructive process influenced by context, social connections, and internal wrestling with cognitive dissonance. Bruner (1996) also contributed to this theory of learning, adding the idea of scaffolding where previous knowledge and experience is intrinsically linked to the construction of meaning.

Constructivist theory defines learning as an active construction of knowledge and meaning rather than acquisition of information (Papert, 1993). Knowledge is therefore constructed internally based upon the existing knowledge framework. Constructionist theory expands on this definition stating that development of observable artifacts that exemplify knowledge being constructed will create a positive feedback loop whereby development of the artifact promotes construction of knowledge, contributing to further artifact development in a continuous cycle (Papert, 1999). As learners engage with these knowledge artifacts, conceptual shifts take place whereby new knowledge is integrated into the existing framework or the existing framework is re-evaluated and rebuilt in light of that new knowledge (Ackermann, 2001; Narayan et al., 2013).

Constructionist theory promotes learner agency by allowing students authority over artifact development, creating personal significance, and motivating students toward greater achievement. Learning occurs most powerfully when a student creates something of their own design with real-world significance, allowing the transfer of knowledge outside of the educational environment (Brown and King, 2000). Indeed, the knowledge that others will view their work adds value and meaning to the construction of knowledge and knowledge artifacts. Construction of the artifact must challenge the learner, prompting them to engage on a cognitive level and take charge of their own learning (Stager, 2005). Constructionist and constructivist conceptualizations of learning and learning structures encourage learners to engage behaviorally, emotionally, cognitively, and agentically (Sinatra et al., 2015). When learning is viewed as continuous construction of knowledge, learners are encouraged to take their learning beyond the classroom. Learning does not occur simply because of teaching, but as a result of experience, observation, and development of internal knowledge frameworks. Such conceptualizations of learning promotes learner motivation beyond the classroom environment.

Situated Learning Theory

Related to the constructivist theory of learning is the idea that learning is an intrinsically social practice that depends upon the physical and social context of the learner (Wolfson, 1999). Situated learning theory closely echoes constructivist theory in that learning is a developmental process where meaning is actively constructed; however, the emphasis is placed on the social context of the knowledge, and learning occurs through participation and belonging in a community of practice (Lave and Wenger, 1991). Learning is defined as "becoming" in the context of the learning community, where learners engage with their community of practice moving from peripheral participation as a novice to an expert as they contribute to the needs of the community (Figure I.3). Engagement with the community provides varied perspectives, experiences, and knowledge from which to construct meaning. Dialogue between members of the community of practice allow for reflection, critical evaluation of ideas, and novel interpretations of knowledge (Stein, 1998).

If viewed narrowly, this theory asserts that knowledge is specific to the context under which learning occurs, which may present difficulties in transferring knowledge into other settings (Anderson et al., 1996). As such, situated learning can be interrelated with experiential learning where students are immersed in a real-world context to allow utilization of knowledge in extra-academic settings. The goal of learning therefore, is not retention of facts, but construction of meaning and appropriate application of knowledge (Stein, 1998). Situated learning is particularly important for students entering a professional environment to build practical competence necessary for success in the

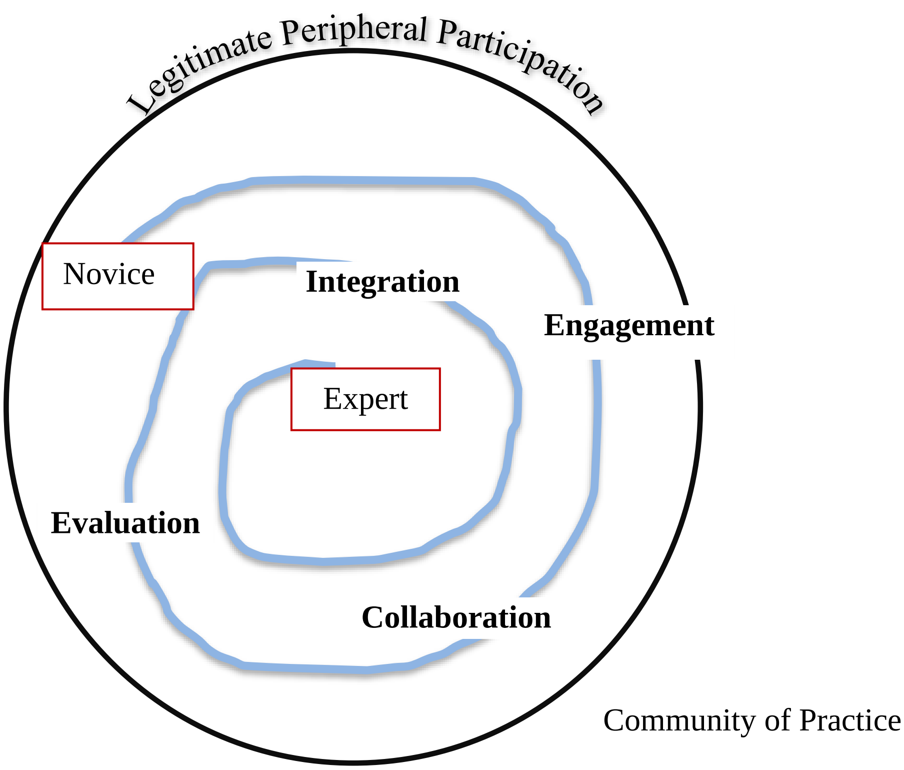


Figure I.3 Situated Learning within a Community of Practice. Adapted with permission (Choi and Donaldson, 2020).

workforce (Kuh et al., 2006). Situating learning outside of the classroom encourages students to consider connections between their lives and studies. These practices encourage competency and confidence which in turn lead to personal and professional success (Kuh, 1994).

Experiential Learning and Field Trips

Experiential learning regularly goes hand in hand with situated learning theory as learners are given the opportunity to apply knowledge in a real-world context. Experiential learning exercises like field trips have long been used in the education system to promote student engagement, provide context for learning, and stimulate interest and motivation (Kolb, 1984; Berte and Jones, 2013; Larsen et al., 2017; Achen et al., 2019). Such experiences outside of the normal classroom environment have been shown to increase self-awareness and confidence of participating students (Kuh, 1993). Additionally, students participating in experiential learning are better able to appropriately apply classroom knowledge in real-world situations. These students gain a sense of purpose and confidence through their ability to apply course material and their exposure to real-world scenarios which require knowledge and skills that they are learning in class (Kuh, 1993). Indeed, experiential learning has been shown to generate long-term impacts on attitudes and future behaviors of students, increasing positive attitudes toward the subject through hands-on experience (Pugsley and Clayton, 2003).

Kolb and Kolb (2017) propose that for the greatest impact from an experiential learning exercise, experiential learning theory must be applied. Experiential learning theory is best described as a cycle (Figure I.4) where students participate in a concrete experience, a field trip, for example. According to experiential learning theory, students' understanding is enhanced through participation in personal reflections that activate autobiographical memory thereby improving retention of information and creating connections between the experience and theoretical concepts (Bruening et al., 2002; Kolb and Kolb, 2017). Indeed, Kolb believes so strongly in the importance of reflection

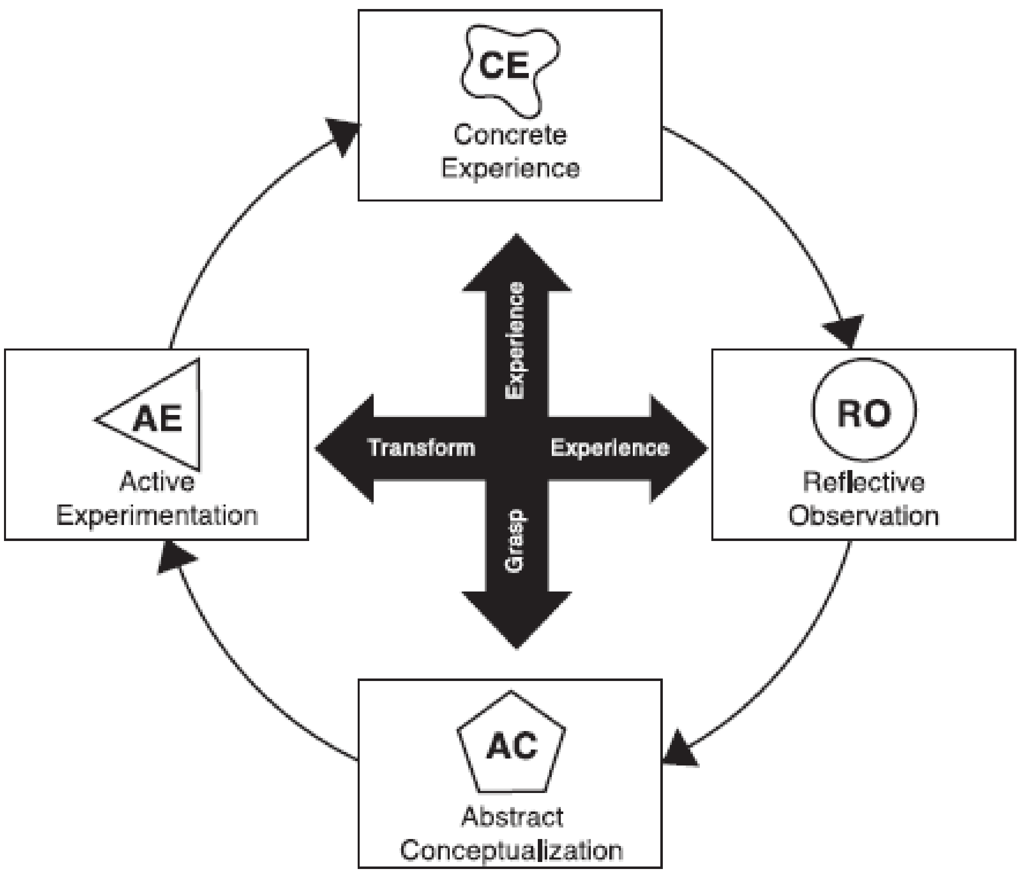


Figure I.4 Experiential Learning Cycle. Reprinted from Kolb and Kolb, 2017

to cement knowledge that he states that without the process of reflection, whatever learning that occurs through an experiential learning exercise is purely happenstance (Kolb and Kolb, 2017). Reflection in turn leads to the assimilation of knowledge and experiences into new abstract conceptualizations which form the basis for deeper understanding and integration with the learner's previously existing knowledge framework (Kolb and Kolb, 2017). Future experiences will be evaluated through the lens of these new conceptualizations which in turn affect future outcomes. Integration of knowledge allows new hypotheses to be formed and the student can begin to plan their next steps leading to new experiences in a continuous cycle (Stern and Powell, 2020).

If effectively implemented, field trips influence long-term career goals and impact cognitive, social, and cultural understanding (Forest and Rayne, 2009). Inclusion of field trips in course development will help to encourage classroom community, and increase understanding of course concepts through active engagement. In a well-developed field trip, all 4 aspects of engagement are promoted as students participate in the trip, connect with faculty and classmates to build community, and observe practical application of course material (Leydon and Turner, 2013). In accordance with experiential learning theory, students should then personalize their knowledge through reflection, considering potential applications.

Kahler et al. (1985) outlined 3 requirements for successful high-impact experiential learning exercises like field trips. These are: (1) observation of phenomena in natural environment, (2) exposure to people and ideas in their natural environment, and (3) conceptualization of learning and education outside of the classroom. With these criteria met, experiential exercises must connect with prior knowledge and experiences for meaningful learning to occur (Bruening et al., 2002). Field trips offer an opportunity for students to see classroom concepts applied in a real world setting, affording them a valuable learning experience that would not be otherwise attainable in the classroom (Bruening et al., 2002). By thinking beyond the classroom, students are able to more readily bridge the gap between theoretical concepts and practical application leading to deeper understanding and personal and professional growth (Higgins et al., 2012).

Experiential learning through field trips sparks personal insights including career interests, perspectives, and applicability of previous course material to students' career aspirations (Kuh, 1993; Slavich and Zimbardo, 2012; Malbrecht et al., 2016). If more widely implemented in higher education, experiential learning activities like field trips have the potential for additional utility in professional development and career preparation. Indeed, employers view first-hand experiences favorably and prefer to hire those who have learned experientially (Wurdinger and Allison, 2017). Other highly marketable soft skills are also promoted through experiential learning like the ability to synthesize information, reasoning skills, collaborative abilities, self-confidence, and self-efficacy (Lei, 2010). Additionally, field trips within a students' prospective industry where students meet and converse with industry professionals allow them to see themselves more readily within a professional setting. Opportunities like these create links between students and industry professionals and aid students in their efforts to form a professional network (Malbrecht et al., 2016). Through firsthand exposure to the reality of various career paths, students are able to see where they may fit into a future profession or may be exposed to a career path not previously considered (Downey, 2012; Higgins et al., 2012; Malbrecht et al., 2016).

Despite positive personal, educational, and professional outcomes, experiential learning exercises like field trips are underutilized in higher education (Higher Education Research Institute, 2011; Wurdinger and Allison, 2017). Primary challenges to incorporating field trips into course curricula are logistical in nature with an extra burden of time, expense, administrative roadblocks, and liability (Higgins et al., 2012). Despite these challenges, I believe that benefits gained from such experiences outweigh the cost.

Collaborative learning

In addition to experiential learning outside of the classroom environment, collaborative learning has been identified as one of 10 high-impact pedagogical strategies influencing student engagement and success (Kuh, 2008b). Collaborative learning activities are based upon the theory that learning is naturally social (Gerlach, 1994), and more effective learning takes place through the exchange of ideas and expertise (Jiake et al., 2010). Peer-to-peer interactions encourage the exchange of ideas and perspectives which clarify concepts and deepen understanding among peers (Cheung et al., 2008). Students also learn more effectively through interactions with their peers as they work together to construct meaning. Collaboration with others in a community of practice contributes to greater engagement in that community and helps to advance students from novice to expert designations.

Collaborative learning facilitates situated learning theory in situations where social context and interaction is an important component of building knowledge

(Dennen, 2000). Although the terms are often used interchangeably, collaborative learning differs from cooperative learning as the emphasis in the learning process is placed not on individual contributions to the goal, but by student-to-student interactions in pursuit of the goal (McInnerney and Roberts, 2009). For students to truly learn collaboratively, the instructor must take a step back into a facilitator role, allowing students agency over the direction of their learning without direct oversight (Bruffee, 1999). By contrast, cooperative learning allows the instructor to maintain control of the process to accomplish a specific end-product. Cooperative learning activities place greater focus on individual contributions to the group's product rather than the process of building knowledge as a group (Panitz, 1996). Collaborative learning actively engages students in the learning process, contributing to their social development, critical thinking, and motivation in the course (Panitz, 1999; Kilgo et al., 2015). Peer interactions also contribute to more global perspectives as students encounter diversity of thought and experience among their classmates (Kuh et al., 2006; Kuh, 2008a).

In a collaborative learning situation, learning is stimulated through discussion as students must justify their actions and describe their thinking processes to their group, thus allowing for personal reflection and evaluation of knowledge (McInnerney and Roberts, 2009). Through collaboration, students recognize the value of their peers' knowledge and experience, promoting appreciation of diversity, interpersonal communication, and personal accountability (Johnson and Johnson, 1994; Panitz, 1999; Kuh et al., 2006; Jiake et al., 2010; Millis, 2010). Students that work collaboratively also develop a support system amongst their peers, creating a more positive environment for learning (Panitz, 1999). Collaborative learning engages students behaviorally, emotionally, cognitively, and agentically, building confidence and improving academic outcomes.

Collaboration is an important skill that many employers have identified as vital to the workplace (Barron, 2000; Colbeck et al., 2000), and in fact, expect students to develop collaborative skills prior to entering the workforce (Coleman, 1999). Thus, it is important to the professional development of students to learn to work productively and efficiently with their peers. Students who participate in collaborative learning are more prepared to enter a workplace environment and deal effectively with unforeseen circumstances and interpersonal relationships in their professional lives (Kuh et al., 2006).

One method by which collaboration can be encouraged is peer-review. Collaborative learning through peer-review promotes development of professional skills, as the ability to both give and receive constructive feedback are valuable skills in the workplace (Coleman, 1999). Peer-review also provides an opportunity for students to think critically about information and methods of presentation chosen by their classmates, providing a form of self-assessment (Pelaez, 2001). By evaluating each other’s work, students are exposed to new methods of explanation or instruction by which to improve their own mental models. Consequently, students tend to improve their own course performance and interpersonal communication skills when both giving and receiving peer-feedback (Nicol et al., 2014).

Visual Model-Based Learning

Engagement can also be promoted in traditional course settings through learning activities which challenge students to expend effort to integrate complex concepts and connect them to future learning experiences. Such activities promote behavioral, emotional, and cognitive engagement in the course. Use of visual model-based reasoning to create learning activities is one example. Visual-model based reasoning is founded in model-based reasoning theory under the premise that humans naturally create mental models to conduct thought experiments or understand new concepts (Nersessian, 1999). Historically, scientists have represented new ideas using models. These models can then be manipulated to test theories, solve problems, or generate inferences. Models are also a useful tool to communicate scientific findings to others (Nersessian, 2002; Ifenthaler and Seel, 2013).

Creation of visual models as a tool for learning has been used extensively in STEM courses like physics, chemistry, and to some extent in histology (Cogdell et al., 2012; Quillin and Thomas, 2015) to illustrate ideas, cycles, mechanisms, or systems (Luckie et al., 2011). Visual models and their development can be used as a tool for reasoning, helping students to construct mental models to foster deeper understanding of complicated ideas (Ainsworth, 2010; Quillin and Thomas, 2015). Creation of a visual representation of a complex idea requires that students interpret and personalize knowledge, working creatively to adapt and illustrate their knowledge in an appropriate format (Damyanov and Tsankov, 2018). Students' ability to create mental and visual models is a predictor of their ability to apply their knowledge in the appropriate context

(Damyanov and Tsankov, 2018). Additionally, through creation of a knowledge artifact, meaning is actively constructed (Papert and Harel, 1991) promoting student agency, engagement, and understanding of the subject. Drawing visual models facilitates construction of self-explanations which can be used to overcome gaps in presented material, organize and integrate knowledge, and generate inferences, predicting future phenomena (Ainsworth, 2010; Ainsworth et al., 2011).

Drawing increases engagement of students with course material, resulting in improved academic performance (Cogdell et al., 2012). Drawing in science can also help to identify misconceptions about presented material which obstruct meaningful learning as students are able to more readily observe how previously abstract concepts do or do not fit together (Köse, 2008). As such, visual modeling can be used as a tool to stimulate conceptual change and more complete and permanent understanding of complex ideas (Quillin and Thomas, 2015). Student generated visual models may also be used as a cue to promote recall, thus improving performance on course assessments (Beveridge and Parkins, 1987).

Visual modeling is an important component of scientific discovery and creation of visual models promotes scientific literacy among students (Schwarz et al., 2009; Long et al., 2014; Quillin and Thomas, 2015). Effectiveness of visual modeling can be supported by teaching strategies which encourage learners to actively process material and demonstrate their understanding through drawing. Students learn best with a combination of visual and verbal information, and by combining verbal and written instruction with student created visual models, drawing becomes a complement to mental models and self-explanations generated by the student as students take ownership of their knowledge (Ainsworth, 2010).

Design-Based Research

A common criticism of educational research is a disconnection between research and practice which can lead to impractical interventions that fail to account for setting or context of learning, or extrinsic and intrinsic factors influencing the learner (Anderson and Shattuck, 2012). As learning and cognition cannot be separated from context, such interventions may look good on paper, but fail to deliver results in an uncontrolled setting (Robinson, 1998; Barab and Squire, 2004). Alternatively, educational research, if not based in theory cannot be generalized or used to influence future classroom practices outside of the context in which research was conducted. Among educational researchers, there is a balance that must be struck between practical, locally applicable knowledge and more widely generalizable, theory-based knowledge (Sandoval and Bell, 2004). Design-based research can be used to bridge the gap between learning theory and practice (Design-Based Research Collective, 2003). This type of research is a formalization of methodology naturally employed by many instructors to improve teaching practices and classroom outcomes.

Design-based research employs a multi-iterative approach to evaluate and modify learning interventions in a manner that is grounded in learning theory and supported by evidence (Design-Based Research Collective, 2003). Using a design-based approach in education allows researchers to systematically revise and improve learning activities through multiple iterations to deliver a high-impact learning experience whose effectiveness has been empirically validated (Sawyer, 2005). Future iterations rely on results of the previous, after which the activity undergo revision, the new design is implemented, and the results analyzed again. Each revision and results can be used to refine the original theory upon which the activity was built (Design-Based Research Collective, 2003). Design-based research continues in a repeating cycle that is illustrated in Figure I.5.

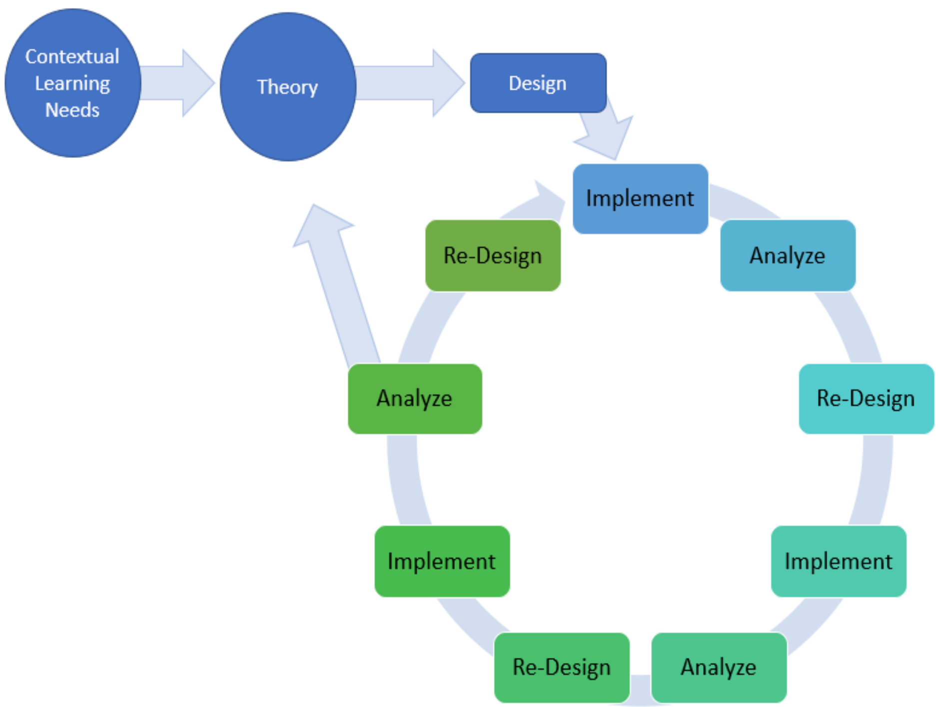


Figure I.5 Continual innovation in design-based research. Reprinted with permission from Donaldson, 2021.

This approach allows researchers across disciplines to evaluate and develop learning theories and establish efficacy of instructional interventions. Design-based research is useful in education as it evolves with the class and the situational context of the learner, taking for granted that with the myriad of factors that can affect learning, interventions may not go as planned. Rather, a design-based approach allows continuous revision of both the intervention and the theory upon which the intervention was based, with the potential to incorporate new revelations as they occur (Hoadley, 2004). This simultaneously promotes adherence to the original research question and learning theory, while demonstrating practical applications of the theory and approach that endure the complexity and challenges of an everyday learning environment (Shavelson et al., 2003; Hoadley, 2004). In this way, design-based research marries theory to practice, allowing development of effective interventions that hold up in a practical environment (Joseph, 2004; Easterday et al., 2014). Additionally, students are encouraged to provide feedback on interventions to affect future iterations. By involving students through feedback in the design process they are encouraged to actively participate in development of the learning activity, promoting agentic engagement (Collins, 1999).

Conclusion

Engagement and meaningful learning are complex and cannot be achieved through the application of a single perfect pedagogical strategy or instructional intervention. Individual characteristics of the learner, goals of the instructor, and the context of learning must be considered to develop appropriate pedagogical or intervention strategies to enhance engagement. As engagement is closely linked to learning outcomes, it is essential that the instructor carefully considers their approach. Engagement can be fostered through a variety of means; it is up to the instructor to determine which approach is most appropriate and beneficial for their purposes. It is the task of the modern educator to reach students and create an environment that allows for exploration and conceptual change to deepen understanding. To accomplish this, it is important to understand the factors which influence learning and the variety of scientifically verified methods to determine the most effective approach to engage and motivate students to success. The following studies explore various methods of increasing student engagement using non-traditional and traditional methods in STEM courses within the animal science discipline.

References

Achen, R. M., C. Warren, A. Fazzari, H. Jorich, and K. Thorne. 2019. Evaluating Graduate Student Out-of-Class Learning: The Professional Field Trip. International Journal of Teaching and Learning in Higher Education 31(1):96-107.

Ackermann, E. 2001. Piaget's constructivism, Papert's constructionism: What's the difference. Future of learning group publication 5(3):438.

Ainsworth, S. 2010. Improving learning by drawing. In: Proceedings of the 9th International Conference of the Learning Sciences-Volume 2. p 167-168.

Ainsworth, S., V. Prain, and R. Tytler. 2011. Drawing to learn in science. Science 333(6046):1096-1097.

Anderson, J. R., L. M. Reder, and H. A. Simon. 1996. Situated learning and education. Educational researcher 25(4):5-11.

Anderson, T., and J. Shattuck. 2012. Design-based research: A decade of progress in education research? Educational researcher 41(1):16-25.

Barab, S., and K. Squire. 2004. Design-based research: Putting a stake in the ground. Journal of the Learning Sciences 13(1)

Barron, B. 2000. Achieving coordination in collaborative problem-solving groups. The journal of the learning sciences 9(4):403-436.

Berte, E., and K. Jones. 2013. The field trip as an experiential teaching strategy to promote reflective learning. Journal of the Academy of Business Education 14

Beveridge, M., and E. Parkins. 1987. Visual representation in analogical problem solving. Memory & Cognition 15(3):230-237.

Brown, S. W., and F. B. King. 2000. Constructivist pedagogy and how we learn: Educational psychology meets international studies. International Studies Perspectives 1(3):245-254.

Bruening, T. H., J. Lopez, D. F. McCormick, and D. R. Dominguez. 2002. Active learning: The impact on students participating in an extended field trip to Puerto Rico. Journal of Agricultural Education 43(4):67-75.

Bruffee, K. A. 1999. Collaborative learning: Higher education, interdependence, and the authority of knowledge. ERIC.

Bruner, J. 1996. The culture of education Cambridge, MA: Harvard University. Burnett, C., Merchant, G., Pahl, K. & Rowsell, J.(2012). The (im) materiality of

Bryson, C., and L. Hand. 2007. The role of engagement in inspiring teaching and learning. Innovations in education and teaching international 44(4):349-362.

Chaplin, S. B., and J. M. Manske. 2005. A theme-based approach to teaching nonmajors biology. Journal of College Science Teaching 35(1):47.

Cheung, W. S., K. F. Hew, and C. S. L. Ng. 2008. Toward an understanding of why students contribute in asynchronous online discussions. Journal of Educational Computing Research 38(1):29-50.

Choi, D. and J. P. Donaldson. 2020. Identity Theory Overview. (Accessed 5.11.2021)

Choi, D., and J. P. Donaldson. 2020. Situated Learning Overview. (Accessed 5.11.2021).

Christie, H., L. Tett, V. E. Cree, J. Hounsell, and V. McCune. 2008. 'A real rollercoaster of confidence and emotions': Learning to be a university student. Studies in higher education 33(5):567-581.

Cogdell, B., B. Torsney, K. Stewart, and R. A. Smith. 2012. Technological and traditional drawing approaches encourage active engagement in histology classes for science undergraduates. Bioscience Education 19(1):1-15.

Colbeck, C. L., S. E. Campbell, and S. A. Bjorklund. 2000. Grouping in the dark: What college students learn from group projects. The Journal of Higher Education 71(1):60-83.

Coleman, J. 1999. Groupware: Collaboration and knowledge sharing. In: J. Liebowitz, editor, Knowledge management handbook. CRC press, Boca Raton. p. 12.11-12.15.

Collins, A. 1999. The changing infrastructure of education research. Issues in education research:289-298.

Damyanov, I., and N. Tsankov. 2018. The role of infographics for the development of skills for cognitive modeling in education. International Journal of Emerging Technologies in Learning (iJET) 13(1):82-92.

Dennen, V. P. 2000. Task structuring for on-line problem based learning: A case study. Journal of Educational Technology & Society 3(3):329-336.

Design-Based Research Collective. 2003. Design-based research: An emerging paradigm for educational inquiry. Educational researcher 32(1):5-8.

Donaldson, J. 2018. Conceptual Shift through Constructionist Learning. p 1-6.

Donaldson, J. P. 2020. Conceptualizations of Learning in the Learning Sciences American Educational Research Association Annual Meeting, San Francisco, California.

Downey, W. S. 2012. Experiential learning through industry interaction in a large lecture agribusiness course. NACTA Journal 56(4):7.

Dunlap, J. C., and R. S. Grabinger. 1996. Rich environments for active learning in the higher education classroom. Constructivist learning environments: Case studies in instructional design:65-82.

Dweck, C. 1999. Self-theories: Their role in personality, motivation, and development. Psychology, Philadelphia, PA

Dweck, C. S., and E. L. Leggett. 1988. A social-cognitive approach to motivation and personality. Psychological review 95(2):256.

Dweck, C. S., and D. C. Molden. 2017. Their impact on competence motivation and acquisition. Handbook of competence and motivation: Theory and application 2:135-154.

Easterday, M. W., D. R. Lewis, and E. M. Gerber. 2014. Design-based research process: Problems, phases, and applications. Boulder, CO: International Society of the Learning Sciences.

Forest, K., and S. Rayne. 2009. Thinking outside the classroom: integrating field trips into a first-year undergraduate chemistry curriculum. Journal of chemical education 86(11):1290.

Fosnot, C. T., and R. S. Perry. 1996. Constructivism: A psychological theory of learning. Constructivism: Theory, perspectives, and practice 2(1):8-33.

Fraefel, U. 2014. Professionalization of pre-service teachers through university-school partnerships. In: Conference Proceedings of WERA Focal Meeting, Edinburgh

Gerlach, J. M. 1994. Is This Collaboration? New directions for teaching and learning 59:5-14.

Handelsman, M. M., W. L. Briggs, N. Sullivan, and A. Towler. 2005. A measure of college student course engagement. The Journal of Educational Research 98(3):184-192.

Hanrahan, M. U. 2002. Learning science: Revisiting humanist dimensions of intellectual engagement. Australasian Science Education Research Association

Higher Education Research Institute. 2011. Faculty Survey. Office of Planning and Institutional Research.

Higgins, N., E. Dewhurst, and L. Watkins. 2012. Field trips as short-term experiential learning activities in legal education. The Law Teacher 46(2):165-178. doi: 10.1080/03069400.2012.681231

Hoadley, C. M. 2004. Methodological alignment in design-based research. Educational psychologist 39(4):203-212.

Ifenthaler, D., and N. M. Seel. 2013. Model-based reasoning. Computers & education 64:131-142.

Jiake, L., Z. Wei, and W. Xuan. 2010. Design and evaluation of a wiki-based collaborative learning environment for colleges computers compulsory education. In: 2010 5th International Conference on Computer Science & Education. p 695-699.

Johnson, D. W., and R. T. Johnson. 1994. Learning Together. In: S. Sharan, editor, Handbook of cooperative learning methods No. 51. Greenwood Press/Greenwood Publishing Group. p. 65.

Joseph, D. 2004. The practice of design-based research: Uncovering the interplay between design, research, and the real-world context. Educational psychologist 39(4):235-242.

Kahler, A., B. Morgan, G. Holmes, and C. Bundy. 1985. Methods in adult education . Danville, IL: The Interstate Printer & Publishers. Inc.

Kahu, E. R. 2013. Framing student engagement in higher education. Studies in higher education 38(5):758-773.

Kaplan, A., and J. K. Garner. 2017. A complex dynamic systems perspective on identity and its development: The dynamic systems model of role identity. Developmental psychology 53(11):2036.

Kilgo, C. A., J. K. E. Sheets, and E. T. Pascarella. 2015. The link between high-impact practices and student learning: Some longitudinal evidence. Higher Education 69(4):509-525.

Kolb, A. Y., and D. A. Kolb. 2017. Experiential learning theory as a guide for experiential educators in higher education. Experiential Learning & Teaching in Higher Education 1(1):7-44.

Kolb, D. 1984. Experiential Learning, Englewood cliffs: Ed. Prentice Hall.

Köse, S. 2008. Diagnosing student misconceptions: Using drawings as a research method. World Applied Sciences Journal 3(2):283-293.

Kuh, G. D. 1993. In their own words: What students learn outside the classroom. American Educational Research Journal 30(2):277-304.

Kuh, G. D. 1994. Student Learning Outside the Classroom: Transcending Artificial Boundaries. ASHE-ERIC Higher Education Report No. 8.

Kuh, G. D. 2003. What we're learning about student engagement from NSSE: Benchmarks for effective educational practices. Change: The Magazine of Higher Learning 35(2):24-32.

Kuh, G. D. 2008a. High-impact educational practices: What they are, who has access to them, and why they matter. Association of American Colleges and Universities 14(3):28-29.

Kuh, G. D. 2008b. High-impact educational practices: What they are, who has

access to them, and why they matter. AAC&U, Washington, D.C. .

Kuh, G. D., J. L. Kinzie, J. A. Buckley, B. K. Bridges, and J. C. Hayek. 2006. What matters to student success: A review of the literature. National Postsecondary Education Cooperative Washington, DC.

Larsen, C., C. Walsh, N. Almond, and C. Myers. 2017. The “real value” of field trips in the early weeks of higher education: the student perspective. Educational Studies 43(1):110-121.

Lave, J., and E. Wenger. 1991. Situated learning: Legitimate peripheral participation. Cambridge university press.

Lei, S. A. 2010. Field trips in college biology and ecology courses: revisiting benefits and drawbacks. Journal of Instructional Psychology 37(1)

Leydon, J., and S. Turner. 2013. The challenges and rewards of introducing field trips into a large introductory geography class. Journal of Geography 112(6):248-261.

Long, T. M., J. T. Dauer, K. M. Kostelnik, J. L. Momsen, S. A. Wyse, E. B. Speth, and D. Ebert-May. 2014. Fostering ecoliteracy through model-based instruction. Frontiers in Ecology and the Environment 12(2):138-139.

Luckie, D., S. H. Harrison, and D. Ebert-May. 2011. Model-based reasoning: using visual tools to reveal student learning. Advances in Physiology Education 35(1):59-67.

Malbrecht, B. J., M. G. Campbell, Y.-S. Chen, and S.-L. Zheng. 2016. Teaching outside the classroom: field trips in crystallography education for chemistry students. Journal of Chemical Education 93(9):1671-1675.

McInnerney, J. M., and T. S. Roberts. 2009. Collaborative and cooperative Learning, Encyclopedia of Distance Learning, Second Edition. IGI Global. p. 319-326.

Millis, B. J. 2010. Why faculty should adopt cooperative learning approaches. Cooperative learning in higher education: Across the disciplines, across the academy 10

Narayan, R., C. Rodriguez, J. Araujo, A. Shaqlaih, and G. Moss. 2013. Constructivism—Constructivist learning theory.

National Research Council, S. Donovan, and J. Bransford. 2005. How students learn. National Academies Press.

Nersessian, N. J. 1999. Model-based reasoning in conceptual change, Model-based reasoning in scientific discovery. Springer. p. 5-22.

Nersessian, N. J. 2002. The cognitive basis of model-based reasoning in science. The cognitive basis of science:133-153.

Newmann, F. M. 1992. Student engagement and achievement in American secondary schools. ERIC.

Nicol, D., A. Thomson, and C. Breslin. 2014. Rethinking feedback practices in higher education: a peer review perspective. Assessment & Evaluation in Higher Education 39(1):102-122.

Olson, S., and D. G. Riordan. 2012. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. Executive Office of the President

Oyserman, D., D. Bybee, and K. Terry. 2006. Possible selves and academic outcomes: How and when possible selves impel action. Journal of personality and social psychology 91(1):188.

Panitz, T. 1996. A definition of collaborative vs cooperative learning.

Panitz, T. 1999. The Case for Student Centered Instruction via Collaborative Learning Paradigms.

Papert, S. 1993. The children's machine: Rethinking school in the age of the computer. ERIC.

Papert, S. 1999. Eight big ideas behind the constructionist learning lab. Constructive technology as the key to entering the community of learners:4-5.

Papert, S., and I. Harel. 1991. Situating constructionism. Constructionism 36(2):1-11.

Pelaez, N. J. 2001. Calibrated peer review in general education undergraduate human physiology. In: Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science, Costa Mesa, CA. p 1518-1530.

Piaget, J. 1977. The development of thought: Equilibration of cognitive structures.(Trans A. Rosin). Viking.

Piaget, J., and M. T. Cook. 1952. The origins of intelligence in children.

Pugsley, K. E., and L. H. Clayton. 2003. Traditional lecture or experiential learning: changing student attitudes. Slack Incorporated Thorofare, NJ.

Quillin, K., and S. Thomas. 2015. Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. CBE—Life Sciences Education 14(1):es2.

Robinson, V. M. 1998. Methodology and the research-practice gap. Educational researcher 27(1):17-26.

Sandoval, W. A., and P. Bell. 2004. Design-based research methods for studying learning in context: Introduction. Educational psychologist 39(4):199-201.

Sawyer, R. K. 2005. The Cambridge handbook of the learning sciences. Cambridge University Press.

Schunk, D. 2004. Learning theories: An educationational perspective. Upper.

Schwartz, S. J., V. L. Vignoles, and K. Luyckx. 2011. Epilogue: What’s next for identity theory and research. Handbook of identity theory and research:933-938.

Schwarz, C. V., B. J. Reiser, E. A. Davis, L. Kenyon, A. Achér, D. Fortus, Y. Shwartz, B. Hug, and J. Krajcik. 2009. Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching 46(6):632-654.

Shavelson, R. J., D. C. Phillips, L. Towne, and M. J. Feuer. 2003. On the science of education design studies. Educational researcher 32(1):25-28.

Sinatra, G. M., B. C. Heddy, and D. Lombardi. 2015. The Challenges of Defining and Measuring Student Engagement in Science. Educational Psychologist 50(1):1-13. doi: 10.1080/00461520.2014.1002924

Skinner, E., E. Saxton, C. Currie, and G. Shusterman. 2017. A motivational account of the undergraduate experience in science: brief measures of students' self-system appraisals, engagement in coursework, and identity as a scientist. International Journal of Science Education 39(17):2433-2459.

Slavich, G. M., and P. G. Zimbardo. 2012. Transformational teaching: Theoretical underpinnings, basic principles, and core methods. Educational psychology review 24(4):569-608.

Stager, G. 2005. Papertian constructionism and the design of productive contexts for learning. In: Proceedings of EuroLogo. p 43-53.

Stein, D. 1998. Situated learning in adult education. ERIC Clearinghouse on Adult, Career, and Vocational Education, Center on ….

Turner, J. C., K. J. Reynolds, P. Van Lange, A. Kruglanski, and E. Higgins. 2012. Handbook of theories of social psychology.

Velayutham, S., J. Aldridge, and B. Fraser. 2011. Development and validation of an instrument to measure students' motivation and self-regulation in science learning. International Journal of Science Education 33(15):2159-2179.

Vygotsky, L. S. 1980. Mind in society: The development of higher psychological processes. Harvard university press.

Wolfson, L. 1999. Learning through service: Community service learning and situated learning in high school, University of British Columbia.

Wurdinger, S., and P. Allison. 2017. Faculty perceptions and use of experiential learning in higher education. Journal of e-learning and Knowledge Society 13(1).

CHAPTER II

TEXAS PANHANDLE BEEF PRODUCTION TOUR, A HIGH-IMPACT MINIMESTER COURSE IN ANIMAL SCIENCE

Synopsis

Many Animal Science students have little exposure to working livestock production systems prior to entering college. As such, they can lack insight into day-to-day challenges and rationale behind decision making in these systems, opening the door for adoption of misconceptions frequently promoted in popular press. Additionally, students identify lack of first-hand knowledge and experience in the industry as a challenge to their educational success. Field trips stimulate interest and motivation, provide context for learning, and influence long-term career goals, but are underutilized in higher education. Potential impact of such experiences prompted creation of the Texas Panhandle Beef Production Tour, a 2-credit hour course that takes place during the spring minimester. To cement learning through reflection, students were asked to respond to a series of questions before, during, and after visiting beef production sites in the Texas Panhandle to probe preconceptions, observations, and outcomes of the experience. We then performed a retroactive evaluation of these reflections (n=22) to determine cogent themes. Emergent themes included surprise at the intensive systems of data collection and management and the level of technology used at each site. Cattle were calmer and more comfortable than expected at the feedlots, dairy, and packing plants visited. Students expressed new appreciation and understanding of course material and a desire to share their insights with others after completing the tour. Finally,

participants gained a broader view of industry opportunities and returned with renewed motivation to pursue additional hands-on opportunities. Participation in this course provided valuable insight into the livestock production industry and motivated students to explore new career options and address their own preconceptions of the industry through independent inquiry. Creation of similar courses may be useful to address misconceptions, create personal connections with course material, and broaden career interests in animal science students.

Introduction:

Compressed courses

Minimester courses have been incorporated into the curricula of many universities as a means to accelerate learning and to provide productive options to fill the time between semesters (Мадюк, 2020). Compressed courses like these yield similar outcomes to traditional 15-week courses as students complete minimester courses with comparable foundational knowledge, skill development, and confidence (Homeyer and Brown, 2002). A minimester course format offers unique opportunities for the incorporation of high-impact learning experiences like experiential learning activities. Students value the inclusion of experiential learning opportunities like field trips in compressed courses to stimulate active learning and more complete immersion in course material (Williamson III, 2017). Additionally, field trips promote personal connections with course material and if students feel that they can apply knowledge either personally or professionally, they are more likely to retain information and report satisfaction with intensive minimester courses (Scott, 1996).

Experiential Learning

Experiential learning and field trips have long been used in the education system to provide context for learning and stimulate student interest and motivation (Larsen et al., 2016). As early as 1916, Dewey posited that experience plays a central role in the learning process, as theory only becomes relevant through experience. Unfortunately, experiential learning through field trips is currently underutilized in higher education (Higher Education Research Institute, 2011; Wurdinger and Allison, 2017). In primary and secondary students, participation in field trips influences long-term career goals and impacts cognitive, social, and cultural understanding (Forest and Rayne, 2009), with similar results likely in higher education. Field trips also can be used to spark personal insights including career interests, perspectives, and applicability of previous course material to career aspirations (Kuh, 1993; Slavich and Zimbardo, 2012; Malbrecht et al., 2016).

Education Challenges

Currently, a challenge to animal science education is the preponderance of misinformation about agriculture and livestock production. Modern consumers are increasingly concerned with the morality of concentrated animal feeding systems (CAFOs; Eurobarometer, 2016). Most of these consumers lack a personal connection with agriculture and have no first-hand knowledge of farming practices (Fraser, 2001; Boogaard et al., 2010; Alonso et al., 2020). Many rely heavily on second-hand sources like news media to formulate their opinions on farming practices, particularly those of CAFOs (Cloke, 1997; Boogaard et al., 2010). Unfortunately, popular press often paints such operations in a negative light creating the perception that they are controlled by corporations concerned only with profit, uninterested in animal welfare, and detrimental to the environment (Fraser, 2001). Currently, pro-agricultural groups tend to respond by categorically refuting these claims and painting an entirely positive picture of animal agriculture that leaves consumers with extremely contradictory narratives, wondering who to trust (Fraser, 2001). This creates a challenge in the animal science classroom, as instructors must unravel strongly held preconceptions about animal production to teach students the scientific, economic, and environmental rationale behind decision making in the livestock industry. This endeavor is made more difficult by the fact that many college students, even those in animal sciences, have had limited to no exposure to working cattle production systems and lack insight into day-to-day challenges and operational protocols from which to promote understanding of the system.

We propose that utilizing experiential learning theory to provide first-hand experience of different aspects of cattle production will increase knowledge and appreciation of the industry, solidify connections with course material, and promote students' awareness of the current gaps in understanding that exist between society and livestock producers (Alonso et al., 2020). Participation in a minimester course comprised entirely of an extended tour of beef production in the Texas Panhandle will afford students a firsthand look into the cattle production industry, providing relevance to course material, and allowing students to reflect on their perceptions of CAFOs and potential career opportunities within the industry (Behrendt and Franklin, 2014; Kolb and Kolb, 2017).

All procedures and data collection were approved by the Texas A&M University Institutional Review Board, IRB2020-0995M.

Methods

Texas Panhandle Beef Production Tour Design

Students (n = 22) enrolled in the cross-listed graduate/undergraduate "Texas Panhandle Beef Production Tour" minimester course, embarked on an extended field trip through the Texas Panhandle in 2018 to visit facilities handling beef production from cow/calf operations through preparation of beef products for retail. Students were encouraged to take advantage of the opportunity to observe aspects of beef production not typically available to the public, and to engage with Animal Science professors and industry professionals during the tour to gain experiential knowledge of the industry.

Data Collection

To evaluate the effect of this minimester field trip on student perceptions, motivations, and career goals, the course instructor collected student reflections regarding their experiences and perspectives. Students were asked to reflect and record their observations and experiences before, during, and after participating in the minimester Texas Panhandle Beef Production Tour. These data were then analyzed retroactively to identify emergent themes.

Table II.1 Demographic information

	Frequency total	**Total %[a]**
Gender		
Male	7	32
Female	15	68
Year		
PhD	4	18
MS	8	36
Senior	13	59
Junior	2	9
Major		
Animal Science	21	95
Biomedical Science	1	4.5
Origin		
Domestic	20	91
International	2	9

[a] Percent totals were calculated by taking the frequency total and dividing by the total number of individuals, n = 22.

Demographic data

Students participating in this minimester course (Table II.1) were comprised of both graduate (32%) and undergraduate students (68%) with a majority from the animal science major (95%) and one biomedical sciences student. Approximately (68%) of students were female. Students of both international (9%) and domestic (91%) origin participated in this course. Although the majority of students were part of the animal science major, most had not had the opportunity to visit large scale concentrated feeding operations or packing plants before participating in this minimester course.

Reflections

Prior to arriving in the Texas Panhandle, students were asked to respond to several prompts to gauge their views on CAFOs, their educational experience, and their perspectives of animal science (Table II.2). These prompts included questions like "What does a feedlot look like?" "What challenges does a packing plant face?" "What do you hope to gain from this trip?" and "What challenges do you have to achieving your educational goals?"

During the trip, students reflected on each experience at the feedlots, dairy, packing plant, and ranch that they visited (Table II.3). Students relayed observations and surprises from each site, as well as challenges discussed by managers and employees of these sites.

At the conclusion of the trip, students reflected on several more prompts to assess perception changes (Table II.4) including, "How have your views on animal science courses changed?" "What will you do as a result of this trip?" and "What did you get out of this trip?"

Data Analysis

Student responses were then analyzed using the Chi (1997) 7 step methodology for qualitative analysis. Responses to reflection prompts were coded using an open coding methodology to identify emerging themes using MAXQDA Analytics Pro (VERBI, 2020), and the frequencies of responses evaluated. Open coding resulted in a total of 227 codes and 1027 coded segments. Responses to each prompt were tallied and rate of each response determined by the frequency of the response divided by total number of responses for the prompt in question.

Results and Discussion

Pre-departure Reflections

Through their pre-departure reflections (Table II.2) students identified the primary challenge to achieving educational goals as a lack of hands-on or industry experience (31.8%) within their normal degree path in animal science. Additionally, students cited a lack of knowledge or confidence about industry careers (22.7%) as a potential roadblock to their future success as animal science professionals. As one student stated,

"I was not raised on a cattle operation and feel that I am at a disadvantage at times."

Students desired opportunities to gain hands-on or industry experience (50.0%) and viewed the Panhandle Beef Production Tour as an opportunity to address their lack of knowledge and firsthand experience to enhance their opportunities for success within animal science.

Table II.2. Student responses to reflection prompts before embarking on the Texas Panhandle Beef Production Tour

Prompt and Response	Frequency Total	Response Total %[a]	Total Student %[b]
What do you hope to gain from this trip?			
Firsthand knowledge of livestock industry	6	37.5	27.3
Networking, job, or internship opportunities	6	37.5	27.3
Clarify career goals	4	25.0	18.2
**Item response total*	*16*		
What is a challenge preventing you from getting everything you can out of your education?			
Lack of hands-on or industry experience	7	46.7	31.8
Lack of knowledge or confidence about careers in the industry	5	33.3	22.7
Personal responsibilities	3	20.0	13.6
Item response total	*15*		
What do you see as a solution to your educational challenges?			
Seek out hands-on or industry opportunities	11	84.6	50.0
Apply for graduate school, research, or internship opportunities	2	15.4	9.1
Item response total	*13*		
What are you most excited to do on this trip?			
Apply knowledge from classes to real world scenarios	5	50.0	22.7
Learn about different sectors of the beef industry	3	30.0	13.6
Network with industry professionals	2	20.0	9.1
Item response total	*10*		
What does a packing plant look like?			
Huge factory	10	47.6	45.5
Fast-paced assembly line	6	28.6	27.2
Cramped and miserable	5	23.8	22.7
Item response total	*21*		

Table II.2 Student responses to reflection prompts before embarking on the Texas Panhandle Beef Production Tour, continued

Prompt and Response	Frequency Total	Response Total %[a]	Total Student %[b]
What challenges does a packing plant face?			
Product safety, biosecurity, and sanitation	10	43.5	45.5
Poor public perception	5	21.7	22.7
Animal health and welfare	4	17.4	18.2
Finding, training, and maintaining employees	4	17.4	18.2
Item response total	*23*		
What does a feedlot look like?			
Cramped, dusty pens of cattle	13	86.6	59.1
Item response total	*15*		
What challenges does a feedlot face?			
Cattle health and welfare	13	34.2	59.1
Facility limitations	11	28.9	50.0
Financial issues	8	21	36.4
Public perception	6	15.8	27.2
Item response total	*38*		
What does a large ranch look like?			
Pastures, expansive space	14	66.7	63.6
Cows and calves in fields	5	23.8	22.7
Corporate owned	2	9.5	9.1
Item response total	*21*		
What challenges does a large ranch face?			
Animal factors	15	38.5	68.2
Financial challenges	13	33.3	59.1
Weather or environment	11	28.2	50.0
Item response total	*39*		

Note. Individual responses to prompts were clustered into categories by theme, counts were made.
[a] Response percent totals were calculated by taking the response statement count and dividing by the total individual responses for the prompt in question.
[b] Student percent totals were calculated by taking the response statement count and dividing by total number of students (n=22)
*Item response total does not match number of students (n=22) as student responses may fall into more than 1 category, or they did not respond to the prompt.

When asked what they hoped to gain from participating in the Panhandle Beef Production Tour, student responses reflected similar themes; 27.3% hoped to gain firsthand knowledge of the cattle industry, an additional 27.3% intended to seek out networking, job, or internship opportunities, while 18.2% of students hoped to clarify their career goals through exposure to the industry and industry professionals. Furthermore, students expressed excitement about the opportunity to apply knowledge learned in their animal science classrooms to real-world scenarios (22.7%), learn about different sectors of the beef industry (13.6%), and network with industry professionals (9.1%).

Ranch

Students imagined ranches as idyllic spaces consisting of large pastures (63.6%) with cows and calves in the fields (22.7%). Several students also mentioned an expectation that most large ranches are corporate owned and operated (9.1%) in accordance with perceptions described by Fraser (2001). Challenges to the success of ranches were identified as animal factors (68.2%) including cattle health, management, and breeding programs. Students cited financial factors (59.1%) like market volatility or land and feed prices, as well as weather (50.0%) as further challenges to ranch operations (Table II.2).

Feedlots

When asked about their perspectives of feedlots, 59.1% of students expected them to be a large facility of many dusty and cramped pens of cattle (Table II.2). Similar to the views of the modern consumer discussed by Fraser (2001), animal science students had a rather negative view of feedlots and other CAFOs, expecting cattle to be *"packed like sardines"* with *"an overabundance of flies and manure."*.

Many students expected cattle health and welfare to be a major issue for feedlots (59.1%), while others cited financial issues (36.4%) such as market volatility or feed prices as a challenge within the feedlot production system. Public perception (27.2%) and facility limitations (50.0%) such as manure management and efficiency were also mentioned as potential challenges to feedlot operations.

Packing Plants

Students characterized packing plants as cramped and miserable places to work (22.7%) imagining a huge factory-like space (45.5%) with a fast-paced assembly line (27.2%) within (Table II.2). Major challenges for packing plants were thought to be product safety concerns such as biosecurity and sanitation (45.5%). They also predicted that poor public perception (22.7%), animal welfare (18.2%), and employee training and retention (18.2%) would present operational challenges in Panhandle packing plants.

During Tour Observations

Students recorded their observations during each site visit (Table II.3), including any surprises, or challenges discussed by professionals at each site. Many people outside of the livestock industry hold images of livestock production as either a bucolic landscape, or unnatural “factory farms” (Boogaard et al., 2010). Under this dualistic view of production practices, modern innovation is categorized as “unnatural” and “bad” while a lack of technology relying mainly on traditional practices is viewed as “good” and “idyllic”. Neither of these disparate images accurately characterizes modern large-scale livestock production. Firsthand experience provides learners with a more nuanced perspective, facilitating reasonable expectations of producers and realistic viewpoints of the value of modern innovation in farming practices (Boogaard et al., 2010).

Table II.3 Frequencies of students' individual response statements by prompt and responses regarding observations during the Texas Panhandle Beef Production Tour.

Prompt and Response	Frequency Total	Response Total %[a]	Student Total %[b]
Packing plant challenges			
Worker hiring, retention and training	18	58.1	81.8
Oversized carcasses	6	19.4	27.3
Plant security, safety, and sanitation	4	12.9	18.2
Protecting reputation	3	9.7	13.6
**Item response total*	*31*		
Packing plant observations and surprises			
Organized, efficient and fast-paced	13	25	59.1
2000+ employees	11	21.2	50.0
Huge, complex	10	19.2	45.5
Process 5000 cattle per day	8	15.4	36.4
Manual labor	7	13.5	31.8
High tech	6	11.5	27.3
Use for all byproducts	4	7.7	18.2
Clean	3	5.8	13.6
Item response total	*52*		
Feedlot challenges			
Maintaining cattle health	11	28.2	50.0
Filling labor positions	7	17.9	31.8
Financial challenges	6	15.4	27.3
Purchasing uniform, healthy cattle	6	15.4	27.3
Negative public perception	5	12.8	22.7
Environment and weather	4	10.3	18.2
Item response total	*39*		

Table II.3 Frequencies of students' individual response statements by prompt and responses regarding observations during the Texas Panhandle Beef Production Tour, continued

Prompt and Response	Frequency Total	Response Total %[a]	Student Total %[b]
Feedlot observations and surprises			
Technologically advanced	11	21.6	50.0
System precision, complexity, and efficiency	9	17.6	40.9
Clean and calm facilities	9	17.6	40.9
Robust research programs on feedlots	8	15.7	36.4
Knowledgeable employees	5	9.8	22.7
Secure, well-tracked medication use	3	5.9	13.6
Healthy comfortable cattle	3	5.9	13.6
Immense amount of data collection	3	5.9	13.6
Item response total	*51*		
Dairy observations and surprises			
Management of facilities efficient, clean and high tech	10	52.6	45.5
Closely monitored comfortable cows	6	31.6	27.2
More cows than expected	3	15.8	13.6
Item response total	*19*		
Ranch observations and surprises			
Huge amount of data collected	11	68.8	50.0
Large, family run using horses	3	18.8	13.6
Always improving	2	12.5	9.1
Item response total	*16*		

Note. Individual responses to prompts were clustered into categories by theme, counts were made.

[a] Percent totals were calculated by taking the response statement count and dividing by the total individual responses for the prompt in question.

[b] Percent totals were calculated by taking the response statement count and dividing by total number of students (n=22)

*Item response total does not match number of students (n=22) as student responses may fall into more than 1 category, or they did not respond to the prompt.

Surprise at the level of technology in use at each site was a common theme among students (27.3%, 50.0%, and 45.5% at the packing plant, feedlot, and dairy respectively). Additionally, students were surprised by the cleanliness and calm environment in the sites visited (13.6%, 40.9% and 27.2% at the packing plant, feedlots, and dairy respectively). These observations are similar to those made by Boogaard et al. (2010) when conducting tours of dairy farms for laypersons in Norway and the Netherlands. Participants in those dairy tours confronted their personal biases and constructed a more balanced and complex opinion of farming and farm operations after experiencing those practices first-hand.

Packing plant

While touring the packing plant, students observed a large and complex system (45.5%) operating efficiently at a face-pace (59.1%; Table II.3). Students mentioned their surprise to learn that the plant they visited employs over 2000 people (50.0%) and much of the work is accomplished manually (31.8%) to process over 5000 cattle each day (36.4%). Interviews with professionals at the packing plant identified major operational challenges in employee hiring, training, and retention (81.8%), of greater concern than students originally surmised. Students were surprised to learn that,

> *"Because it is such a physically demanding job, [packing plants] have to look further for people than cattle."*

As expected by students prior to visiting the plant, sanitation, biosecurity, and safety were identified as operational challenges (18.2%). Packing plant managers also mentioned an unexpected challenge of oversized carcasses (27.3%) caused by a change in feeder market preferences not yet reflected in available equipment or consumer markets.

Feedlot Observations

Student reflections of their experiences at corporate and privately owned feedlots mentioned the precision necessary to keep a complex system of technology, employees and animals running efficiently (40.9%; Table II.3). Also contrary to expectations were the robust research programs present in these feedlots (36.4%), secure and well-tracked medication use (13.6%), and the enormous amount of data collected during daily operations (13.6%). These observations led to personal revelations for some students.

"Research in industry is not something I ever considered. I always just assumed that it was just a thing that Universities did, but I was wrong. This could be yet another path which I could pursue."

Feedlot professionals spoke with students about challenges to feedlot operations including maintaining cattle health and welfare (50.0%) as predicted by students prior to the site visits. Contrary to expectations however, this challenge is met largely prophylactically, rather than through intensive treatment of large numbers of sick animals. Additionally, filling labor positions (31.8%), financial challenges (27.3%) like feed costs and market volatility, and negative public perception (22.7%) were mentioned as daily challenges in feedlot management.

Ranch Observations

Although students mentioned the idyllic, family-run setting of the large ranch they visited (13.6%), a greater impression was made by the huge amount of data collected and intensive management required (50.0%) to maintain cattle health, and genetic progression through the breeding program (Table II.3). This ensures that genetics are always improving to promote meat quality, performance of cattle, and sustainability (9.1%).

"[The ranch owner] *retains ownership of some of his calves through the packer so he knows their performance…to produce the best cattle to perform in all areas of cow-calf, feedlot, and packer to benefit the entire beef industry".*

Post-Return Reflections

At the conclusion of this trip, students reflected on their experiences, perspective changes, and intentions going forward (Table II.4). Experiential learning through field trips is widely accepted as a means to challenge preconceptions and generate attitude and behavioral changes in students (Scarce, 1997; Pugsley and Clayton, 2003; Forest and Rayne, 2009; Behrendt and Franklin, 2014; Alonso et al., 2020), leading to more

Table II.4. Frequencies of students' individual response statements by prompt and responses regarding post-tour perspectives

Prompt and Response	Frequency Total	Response Total %[a]	Student Total %[b]
What did enjoy most about this trip			
First-hand knowledge of industry	8	32.0	36.4
Opportunity to apply classroom knowledge in a real-world setting	6	24.0	27.3
Site visits	5	20.0	22.7
Networking opportunities	5	20.0	22.7
**Item response total*	*25*		
What did you get out of this trip?			
New appreciation and respect for livestock industry	9	27.3	40.9
New perspective of how the beef industry works together	9	27.3	40.9

Table II.4. Frequencies of students' individual response statements by prompt and responses regarding post-tour perspectives

Prompt and Response	Frequency Total	Response Total %[a]	Student Total %[b]
What did you get out of this trip?			
Broadened view of industry opportunities	8	24.2	36.4
Clarified career goals	5	15.2	22.7
Corrected some of my misconceptions	2	6.1	9.1
Item response total	*33*		
How have your views on animal science changed?			
New appreciation and understanding after seeing animal science in action	8	72.8	36.4
Identified area of interest for future	3	27.3	13.6
Item response total	*11*		
What will you do as a result of this trip?			
Take steps to achieve career goals	18	46.2	81.8
Teach others about what I learned	10	25.6	45.5
Seek out more first-hand knowledge and experiences	7	17.9	31.8
Try to understand, asking more questions instead of making assumptions	4	10.3	18.2
Item response total	*39*		

Note. Individual responses to prompts were clustered into categories by theme, counts were made.
[a] Percent totals were calculated by taking the response statement count and dividing by the total individual responses for the prompt in question.
*Item response total does not match number of students (n=22) as student responses may fall into more than 1 category, or they did not respond to the prompt.

positive attitudes toward the subject being studied (Pugsley and Clayton, 2003). Participants on this tour greatly enjoyed gaining first-hand knowledge of the beef industry (36.4%) and valued the opportunity to apply classroom knowledge in a real-world setting (27.3%).

Students are more likely to internalize, assimilate, and retain information when they are actively engaged in experiential learning (Bonwell and Sutherland, 1996). Firsthand experiences allow learners to bridge the gap between theoretical concepts and practical application at greater depths than is possible to achieve through reading books or lecture (Higgins et al., 2012; Leydon and Turner, 2013). Additionally, the opportunity to actively engage and apply course material in a novel manner increases the likelihood of retaining information and grasping complex concepts (Falk and Balling, 1982). As was the case with veterinary students observed by Alonso et al. (2020), firsthand experiences on this tour led to greater appreciation and understanding of animal science courses after seeing class concepts applied in industry (36.4%).

"This trip really did change the way I think about my previous classes…It put them in a whole new perspective of application, and I have a greater appreciation."

Seeing course material applied in a real-world setting also increased motivation for future course work and career preparation (Higgins et al., 2012; Achen et al., 2019; Alonso et al., 2020), reported by students after completing the tour.

"Seeing and hearing about feedstuffs used in real life scenarios stimulated my wanting to learn all I can in this upcoming class."

Exposure to industry through field trips not only provides a frame of reference for previous knowledge, it helps to construct a framework for students to apply knowledge in future courses (Bruening et al., 2002; Higgins et al., 2012) giving relevance to learning by demonstrating the utility of course concepts in practice. This in turn increases students' motivation to learn and seek out more first-hand knowledge or experiences (31.8%). Meaningful firsthand experiences inspire students to share their knowledge and experiences with others (45.5%) as they are able to see the practical value of concepts that may previously have been one dimensional (Cheek et al., 1994; Scarce, 1997; Larsen et al., 2016; Achen et al., 2019). This was demonstrated in student reflections.

"After this trip I was able to see how the things I was taught were applied as a career. This trip made me want to sign up for classes that I didn't intend to take before."

"I can use my experiences on the trip to confront the stigmas some people have placed on the [beef] industry and share my knowledge with them."

Additionally, in accordance with Boogaard et al. (2010) and Alonso et al. (2020), participants identified gaps in their knowledge and understanding of the industry and felt that the tour effectively addressed some of their misconceptions (9.1%). After completing this tour, participants were motivated to ask more questions, seeking to understand rather than making assumptions (18.2%).

"I have my own opinions based on more of what I saw and less off of other people's opinions."

Students returned with a new appreciation for largescale livestock production (40.9%) and greater understanding of the interconnectedness of the beef industry from ranch to packing plant (40.9%), saying,

"I gained a new respect for the beef industry as a whole. All of these people have some tough jobs, and I never knew how many people were behind the production of cattle. I

am impressed with all of them, and I have gained a more thorough knowledge of the beef industry because of them."

Field trips increase feelings of belonging among students within their academic programs, Experiences outside of the classroom increase self-awareness and help students to develop a sense of purpose and optimism for future endeavors (Kuh, 1993). As one student very eloquently put it,

"I'll take home the reminder that agriculture is big, necessary, and has a place for me."

In addition to educational benefits, industry field trips in higher education allow students to explore professional opportunities and prepare to enter the workforce (Achen et al., 2019). By creating an environment where students may engage openly with faculty and industry experts in a professional setting, students are exposed to potential employment opportunities which aids them in defining their personal and professional goals, and allows them to see themselves in a professional setting (Gore and Nelson, 1984; Higgins et al., 2012; Malbrecht et al., 2016). Several participants in the Panhandle Beef Production Tour felt that the trip helped clarify their career goals (22.7%). Through experiences on this tour, other students identified potential interest areas for the future in research or careers (13.6%). When asked what they will do as a result of their experiences on this tour, students were eager to begin taking steps to achieve their career objectives (81.8%) beginning with setting specific goals for career preparedness.

"There are many routes in the animal science/agriculture industry that I have never thought about."

"I have a more open mind on the various careers I can choose from in agriculture, I am going to look into more of what is available to me."

Additionally, networking opportunities provided by these experiences help to create links to faculty and industry professionals which aid students in their transition to the workforce or to graduate or professional school (Downey, 2012; Higgins et al., 2012). The Texas Panhandle Beef Production Tour provides students with the opportunity to visit beef production sites not generally accessible to the public to see course concepts applied in a real-world setting. This course also allows students to engage with faculty and industry professionals beyond interactions typical of career fairs or interviews (Downey, 2012). Such interactions strengthen relationships between the university and industry partners, helping to produce and place high-quality graduates in related positions (Pecen et al., 2018).

Conclusion

Through this minimester course design, students gained valuable insight into livestock production, developed greater appreciation for animal science course material, and were motivated to invest in their learning and seek additional experiential opportunities. Additionally, students made connections with industry professionals and faculty that will aid them in their future endeavors. Creation of similar high-impact minimester courses in animal science and agriculture will be useful to contextualize course material, expand students' prospects for future careers, and develop university-industry relationships. Indeed, such minimester courses will likely prove valuable in any number of disciplines.

References

Achen, R. M., C. Warren, A. Fazzari, H. Jorich, and K. Thorne. 2019. Evaluating Graduate Student Out-of-Class Learning: The Professional Field Trip. International Journal of Teaching and Learning in Higher Education 31(1):96-107.

Alonso, M. E., J. R. Gonzalez Montaña, J. C. Dominguez, and J. M. Lomillos. 2020. Veterinary students´ perceptions of participation in a service-learning activity 6th International Conference on Higher Education Advances (HEAd'20). p 1-8.

Behrendt, M., and T. Franklin. 2014. A review of research on school field trips and their value in education. International Journal of Environmental and Science Education 9(3):235-245.

Bonwell, C. C., and T. E. Sutherland. 1996. The active learning continuum: Choosing activities to engage students in the classroom. New directions for teaching and learning 1996(67):3-16.

Boogaard, B. K., B. B. Bock, S. J. Oosting, and E. Kroch. 2010. Visiting a farm: An exploratory study of the social construction of animal farming in Norway and the Netherlands based on sensory perception. The International Journal of Sociology of Agriculture and Food 17(1):24-50.

Bruening, T. H., J. Lopez, D. F. McCormick, and D. R. Dominguez. 2002. Active learning: The impact on students participating in an extended field trip to Puerto Rico. Journal of Agricultural Education 43(4):67-75.

Cheek, J. G., L. R. Arrington, S. Carter, and R. S. Randell. 1994. Relationship of supervised agricultural experience program participation and student achievement in agricultural education. Journal of agricultural education 35(2):1-5.

Chi, M. T. 1997. Quantifying qualitative analyses of verbal data: A practical guide. The journal of the learning sciences 6(3):271-315.

Cloke, P. 1997. Country backwater to virtual village? Rural studies and 'the cultural turn'. Elsevier.

Dewey, J. 1916. Experience and thinking. Democracy and Education: Free Press, Collier-MacMillan Ltd:139-151.

Downey, W. S. 2012. Experiential learning through industry interaction in a large lecture agribusiness course. NACTA Journal 56(4):7.

Falk, J. H., and J. D. Balling. 1982. The field trip milieu: Learning and behavior as a function of contextual events. The Journal of Educational Research 76(1):22-28.

Forest, K., and S. Rayne. 2009. Thinking outside the classroom: integrating field trips into a first-year undergraduate chemistry curriculum. Journal of chemical education 86(11):1290.

Fraser, D. 2001. The “New Perception” of animal agriculture: Legless cows, featherless chickens, and a need for genuine analysis. Journal of animal science 79(3):634-641.

Gore, J. S., and H. Y. Nelson. 1984. How experiential education relates to college goals and objectives. Evaluation and Program Planning 7(2):143-149.

Higgins, N., E. Dewhurst, and L. Watkins. 2012. Field trips as short-term experiential learning activities in legal education. The Law Teacher 46(2):165-178. doi: 10.1080/03069400.2012.681231

Higher Education Research Institute. 2011. Faculty Survey. Office of Planning and Institutional Research.

Homeyer, L. E., and C. J. Brown. 2002. The Intensive, three week interim semester: Is it effective? TCA Journal 30(2):34-42.

Kolb, A. Y., and D. A. Kolb. 2017. Experiential learning theory as a guide for experiential educators in higher education. Experiential Learning & Teaching in Higher Education 1(1):7-44.

Kuh, G. D. 1993. In their own words: What students learn outside the classroom. American Educational Research Journal 30(2):277-304.

Larsen, C., C. Walsh, N. Almond, and C. Myers. 2016. The “real value” of field trips in the early weeks of higher education: the student perspective. Educational Studies 43(1):110-121. doi: 10.1080/03055698.2016.1245604

Leydon, J., and S. Turner. 2013. The challenges and rewards of introducing field trips into a large introductory geography class. Journal of Geography 112(6):248-261.

Malbrecht, B. J., M. G. Campbell, Y.-S. Chen, and S.-L. Zheng. 2016. Teaching outside the classroom: field trips in crystallography education for chemistry students. Journal of Chemical Education 93(9):1671-1675.

Pecen, R. R., F. Yildiz, and I. I. Basuth. 2018. An Effective Industry-University Partnership to Develop Tomorrow’s Work-force American Society for Engineering Education Annual Conference and Exposition, Salt Lake City, UT.

Pugsley, K. E., and L. H. Clayton. 2003. Traditional lecture or experiential learning: changing student attitudes. Slack Incorporated Thorofare, NJ.

Scarce, R. 1997. Field trips as short-term experiential education. Teaching Sociology 25(3):219-226.

Scott, P. A. 1996. Attributes of high-quality intensive course learning experiences: Student voices and experiences. College Student Journal 30:69-77.

Slavich, G. M., and P. G. Zimbardo. 2012. Transformational teaching: Theoretical underpinnings, basic principles, and core methods. Educational psychology review 24(4):569-608.

Williamson III, K. C. 2017. A comparison between mini-mester and full semester achievement in a construction surveying course. In: Proceedings of the Associated Schools of Construction, 53rd Annual International Conference, Seattle, Washington. p 5-7.

Wurdinger, S., and P. Allison. 2017. Faculty perceptions and use of experiential learning in higher education. Journal of e-learning and Knowledge Society 13(1)

Мадюк, O. 2020. The place of compressed courses in the process of students' training: foreign experience 30th International Scientific and Practical Internet conferences. p 146-148. Uman State Pedagogical University.

CHAPTER III

VISUAL MODELING AS A PEDAGOGICAL STRATEGY IN NUTRITIONAL PHYSIOLOGY ANIMAL SCIENCE COURSE

Synopsis

Nutritional physiology includes a number of complex biological and biochemical processes that can be difficult for students to grasp. It is our belief that students' ability to visually model and explain these processes will increase understanding, retention of knowledge, and their ability to integrate and apply complex nutritional concepts. Creation of visual models as a tool for learning has been used extensively in courses like physics, chemistry, but is underutilized as a science process skill in biological sciences. Creation of visual models helps to make learning visible and to simplify complex concepts. Drawing to learn could have great utility in describing and deepening comprehension of physiological processes like nutrient digestion and utilization. A learning activity was prepared where students created hand-drawn diagrams of nutrient digestion, absorption, and basic utilization to aid in understanding of course concepts. We evaluated the effectiveness of the learning activity through graded assessment, reflections, and surveys and will use student feedback to revise the activity for future semesters. Creating visual models of nutrient digestion increased student understanding and confidence in explaining complex nutritional processes. This activity was made more effective with the inclusion of a writing component that asked students to combine both visual and verbal cognitive processes to increase comprehension.

Introduction

Biological sciences are notoriously difficult for post-secondary students to learn. Students often attempt to memorize facts and compartmentalize information rather than integrating their knowledge to understand complex processes. As biological sciences like physiology are highly integrative disciplines, this approach is insufficient to bring about true learning (Michael, 2007). Wilson and Barrett (2021) suggest the use of functional diagrams as a pedagogical strategy in physiology instruction to improve students' ability to follow complex processes and integrate and apply their knowledge appropriately. Visual models have long been used in science, technology, engineering, and mathematics (STEM) disciplines like physics, chemistry and math to demonstrate mathematical relationships, biochemical cycles, and chemical reactions. (Quillin and Thomas, 2015; Arneson and Offerdahl, 2018). In fact, without the use of visual representations, illustrations, or models, comprehending these subjects would be near to impossible. Visual modeling allows simplification of complex concepts or visualization of phenomena that may otherwise be imperceptible or abstract (Luckie et al., 2011; Arneson and Offerdahl, 2018). As such, visual modeling is an important component of scientific literacy. Although it is important for students to learn to interpret visual representations or models pertaining to scientific subject matter, even greater outcomes can be achieved through active creation of these models, as creation of visual models is both a powerful tool for communication and learning and an important skill in scientific practice (Quillin and Thomas, 2015).

From an educational standpoint, understanding dynamic systems like nutritional physiology and metabolism that are typically difficult for students to grasp can be facilitated through active development of visual models and explanations (Bobek and Tversky, 2016). By actively participating in developing visual models in class through drawing, students are able to organize their thoughts and create self-explanations of their notes and lecture material (Ainsworth, 2010). Additionally, interactions between components of complex systems can be made clearer through visual modeling, enabling students to master these complex relationships (Bobek and Tversky, 2016). Constructing visual models can help students to overcome discrepancies or disparities in course material, and integrate and apply knowledge appropriately to future situations (Ainsworth, 2010; Ainsworth et al., 2011). In fact, the ability of students to create visual models is strongly related to their capacity to apply course material outside of the classroom setting (Damyanov and Tsankov, 2018). Drawing as an educational tool through developing visual models helps students to construct mental models on which to scaffold their knowledge (Luckie et al., 2011). Additionally, construction of visual models helps to facilitate model-based reasoning by which mental models are constructed, manipulated, revised, and used to test theories and observations to generate conclusions (Nersessian, 1999).

While there is a long history of using visual modeling in STEM disciples, use of drawing or creating visual models as a tool for reasoning is not as widely recognized as a skill in biological sciences like nutritional physiology compared to physics or chemistry (National Research Council, 2012; Quillin and Thomas, 2015). Although modeling and simulation is identified as a core competency in biological sciences by the American Association for the Advancement of Science (2011), their definition of modeling is largely mathematical and does not include drawing and creation of diagrams. Furthermore, drawings and illustrations are frequently employed by instructors in biological sciences to foster meaningful learning and understanding, but creating visual models, or drawing to learn, is not a widely recognized science process skill in biological sciences education (Quillin and Thomas, 2015). Quillin and Thomas (2015) advocate for the adoption of visual modeling in the form of drawing to learn as a core skill in biological sciences education as creation of these visual models promotes deeper learning, scientific literacy, and model-based reasoning which can generate conceptual change in science (Jonassen et al., 2005). Within physiology courses, visual modeling as a tool for teaching and learning has not been extensively studied. Therefore, we seek to determine if development of visual models of metabolism in a nutritional physiology course in animal science increases understanding, integration, and ability to apply knowledge.

A significant component of success in this nutritional physiology animal science course is the ability to compare and contrast digestive structures and functions between relevant animal species. It is our belief that by creating visual representations of these nutrient digestion and utilization, students will be able to visualize similarities and differences more clearly using spatial information to help categorize and integrate information into their mental models to cement learning. Drawing to learn in nutritional physiology is expected to increase understanding, integration, and application of knowledge in the course.

All procedures and data collection were approved by the Texas A&M University Institutional Review Board, IRB2021-0350M and IRB2020-0997M, and students provided informed consent for the use of their data.

Methods

Project Design

We have adopted a design-based approach to this project to allow for improvements in project design over multiple semesters. This approach was selected as it echoes the normal process of instruction and allows evaluation and evidence of efficacy of interventions measured through course performance or student feedback. Design-based research follows a multi-iterative approach grounded in learning theory that proceeds in a cycle of design, implementation, analysis, and revision. Each iteration relies on the results of the previous, allowing for incorporation of feedback or unexpected findings which may lead to novel lines of inquiry (Design-Based Research Collective, 2003). This process allows us to generate pedagogical practices that are effective and applicable in a classroom setting. Additionally, involving students in the design process increases student agency and engagement in the course as they impact the flow of instruction for future semesters (Collins, 1999).

Three activities (A, B, and C) were assigned over the course of two semesters (Fall and Spring) in an undergraduate upper-level Principles of Animal Nutrition course of n = 376 and n = 168 respectively. This course studies nutritional physiology including digestion, absorption, and utilization of nutrients in livestock animal species. The goal of each activity was to create a visual representation of nutrient metabolism focusing on carbohydrates, lipids, and proteins, respectively. Students were required to complete 3 copies of each diagram in 2 selected animal species (horse, pig, or cow) and their enterocytes, based upon information provided in class notes and a sample diagram created during class. Diagrams were constructed using a blank template (Figure III.1).

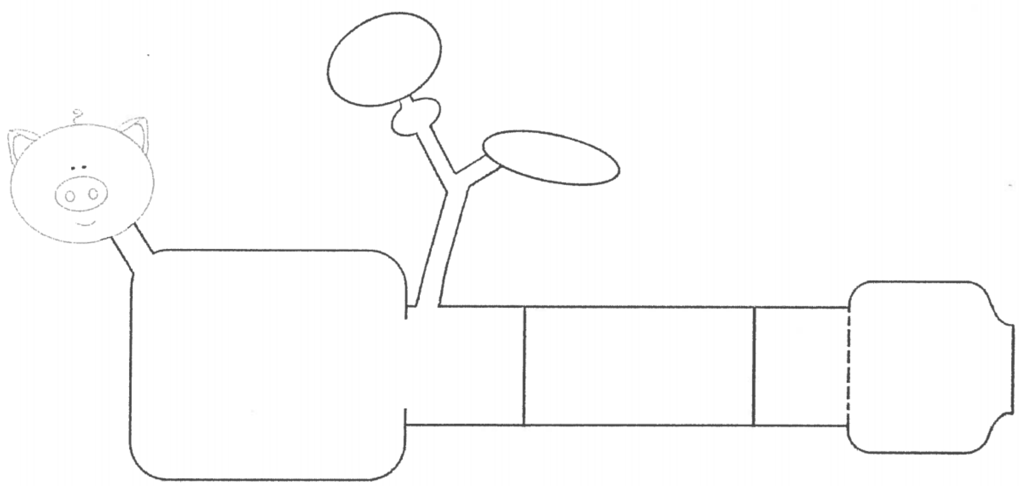


Figure III.1 Example of blank nutrient digestion template

Activities were graded using a prepared rubric (Appendix A). Students also completed Likert scale surveys reflecting on the utility of the activities to their overall course performance, understanding and retention of material, as well as their ability to integrate concepts learned regarding one nutrient to metabolism of another (Appendix C). Upon completion of all activities, students provided feedback that will be used to revise the design of the learning activities in subsequent semesters.

Data Collection and Analysis

Students responded to the following reflection questions at the end of the semester to inform design of future iterations of this learning activity:

1. What aspects of the current iteration of the learning activity worked very well and why?
2. What aspects of the current iteration of the learning activity failed in all cases and why?
3. What design changes should be made to improve future iterations?
4. How have these activities impacted your learning or study methods?

Students also completed Likert scale surveys (Appendix C) after completing the learning activity to assess the impact of the activities on their understanding, comprehension, and perspective in the course.

Reflections were coded in MAXQDA Analytics Pro according to the Chi (1997) methodology for qualitative analysis to identify emergent themes. An open coding methodology was used to categorize reflection responses generating 158 codes and 3729 coded segments. Response frequencies were evaluated. Student reflection responses were used to refine the second iteration of the learning activity. Likert survey response frequencies for each prompt were evaluated and compared using a two-tailed t-test with heteroskedastic variance.

Findings

Iteration 1

Students completed diagrams detailing nutrient digestion, absorption, and utilization in relevant livestock species and their enterocytes (Figure III.2; Figure III.3) and provided feedback over the design of the learning activity (Table III.1).

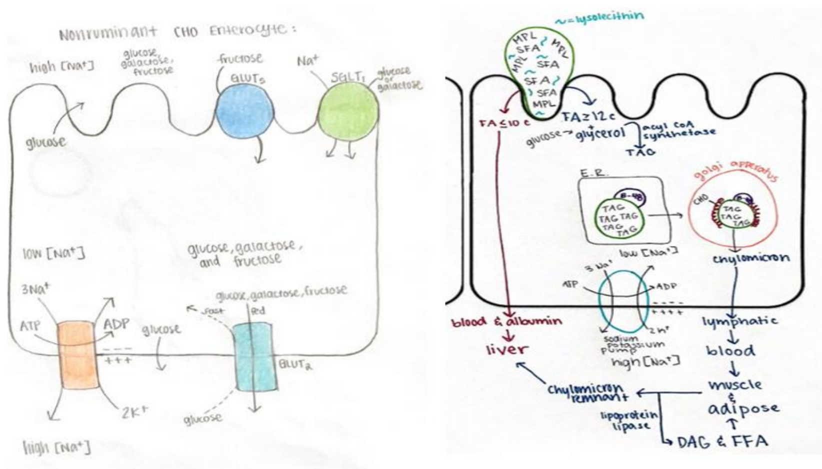


Figure III.2 Sample enterocyte diagrams of nutrient digestion in ruminant and non-ruminant species.

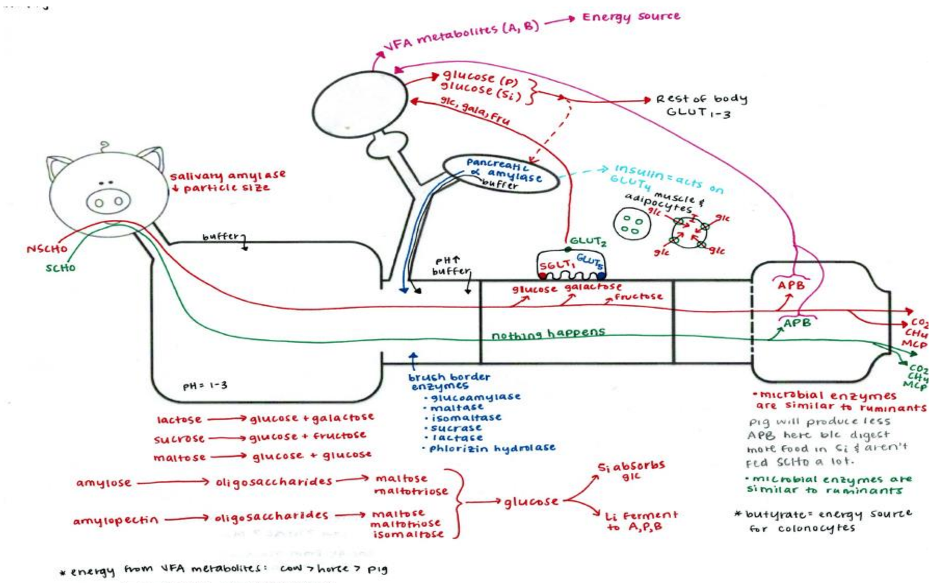


Figure III.3 Sample diagram of carbohydrate digestion, absorption, and utilization in the pig.

After completing the diagrams during the first semester this activity was assigned, 70.9% of students either "Strongly Agreed" or "Agreed" that complex nutritional concepts were easier to grasp (Figure III.5) after completing the activity, while 59.0% indicated that they expected to retain information from the learning activity beyond the next exam (Figure III.6). Additionally, 78.0% and 86.4% of students "Strongly Agreed" or "Agreed" that completing the drawing activity helped to integrate and apply concepts covered in class (Figure III.7) and made it easier to compare concepts learned in one animal with another (Figure III.8), respectively. While 79.7% of students believed that drawing diagrams was a helpful study aid for course exams (Figure III.9), only 35.3% of students indicated that they would use a similar method to study in other courses (Figure III.10).

Although many students found the repetition of the first iteration of this activity to be helpful to their learning process (36.8%), others indicated that they would prefer an assignment that promoted more critical though (22.9%), finding the repetition of creating multiples of the same drawing to be time-consuming and tedious (15.1%).

Table III.1 Student feedback of learning activity design, iteration 1

Prompt and Response	**Frequency Total**	**Total %[a]**
What aspects of this learning activity worked well?		
Repetition	131	36.9
Drawing diagrams helped visualize process of metabolism, tell story	102	28.7
Comparing species was simplified	62	17.5
Able to represent information visually, provided context for notes	31	8.7
Provided copies to study from	11	3.1
Helpful, no explanation	10	2.8
Organizing by color	7	2.0
**Item response total*	*355*	

Table III.1 Student feedback of learning activity design iteration 1, continued

Prompt and Response	Frequency Total	Total %[a]
What aspects of this learning activity failed?		
Nothing	74	28.8
Repetition, want to think more	59	23.0
Time consuming, tedious	39	15.2
More information, detail should be required on diagram	18	7.0
Do not understand diagram after drawing	13	5.1
Difficulty making comparisons between nutrients and species	9	3.5
Do not retain information	9	3.5
Too much information on diagrams	8	3.1
Not enough information given in lecture for diagrams	8	3.1
Would like to complete diagrams for all 3 species	4	1.6
Instructions unclear	4	1.6
Grading is too hard	2	0.8
Not helpful, no explanation	2	0.8
Item response total	*257*	
What design changes should be made to the learning activity for future iterations?		
None	98	37.4
Include writing, explanation component of assignment	44	16.8
Less repetition	31	11.8
Add vocabulary component	18	6.9
Add direct comparison component	10	3.8
Require completion of activity for all 3 species rather than 2/3	10	3.8
Provide larger templates	9	3.4
Provide answers, completed diagram before activity	7	2.7
List everything that should be included, more detailed instructions	6	2.3
Activity due further away from exam	6	2.3
Break down diagrams more	5	1.9
Add a word bank or fill in the blank worksheet	4	1.5
Provide key for abbreviations	3	1.2
Desire more variation in the activity	3	1.2
Grade faster and easier	2	0.8
Provide less information in the instructions	2	0.8
Provide more frequent in-class reminders and assistance	2	0.8
Provide more feedback	2	0.8
Item response total	*262*	

Note. Individual responses to prompts were clustered into categories by theme, counts were made.

[a] Percent totals were calculated by taking the response statement count and dividing by the total individual responses for the prompt in question.

*Item response total does not match number of students (n=301) as student responses may fall into more than 1 category, or they did not respond to the prompt.

Students reported that drawing diagrams helped them to visualize the process of metabolism and tell a complete story that helped them to fill in gaps in understanding (28.7%). Drawing the diagrams helped to simplify comparisons of digestion between species of animals (17.5%) and provided context for notes as students were able to see information represented visually (8.7%).

When asked to suggest improvements to the learning activity for future semesters, 16.8% of students suggested that the addition of a writing component to the assignment would deepen their understanding of the processes they were drawing in the diagrams. Adding a writing component to the assignment in place of repeating the drawings would decrease repetition (16.8%) and potentially allow for direct comparisons to be made between species as a formal part of the assignment (3.8%).

Iteration 2

Taking student feedback into account, we reduced the repetition required during iteration 2 and added a writing component to the assignment asking students to respond to a prompt coinciding with the nutrient in question, in addition to creating a diagram of digestion of the given nutrient in all 3 animal species and their enterocytes (Figure III.4). Written components of the assignment were graded by peer review using the provided rubric to facilitate peer instruction (Appendix B). Students were also asked to highlight the important components of their diagrams discussed in their writing assignments on their drawings.

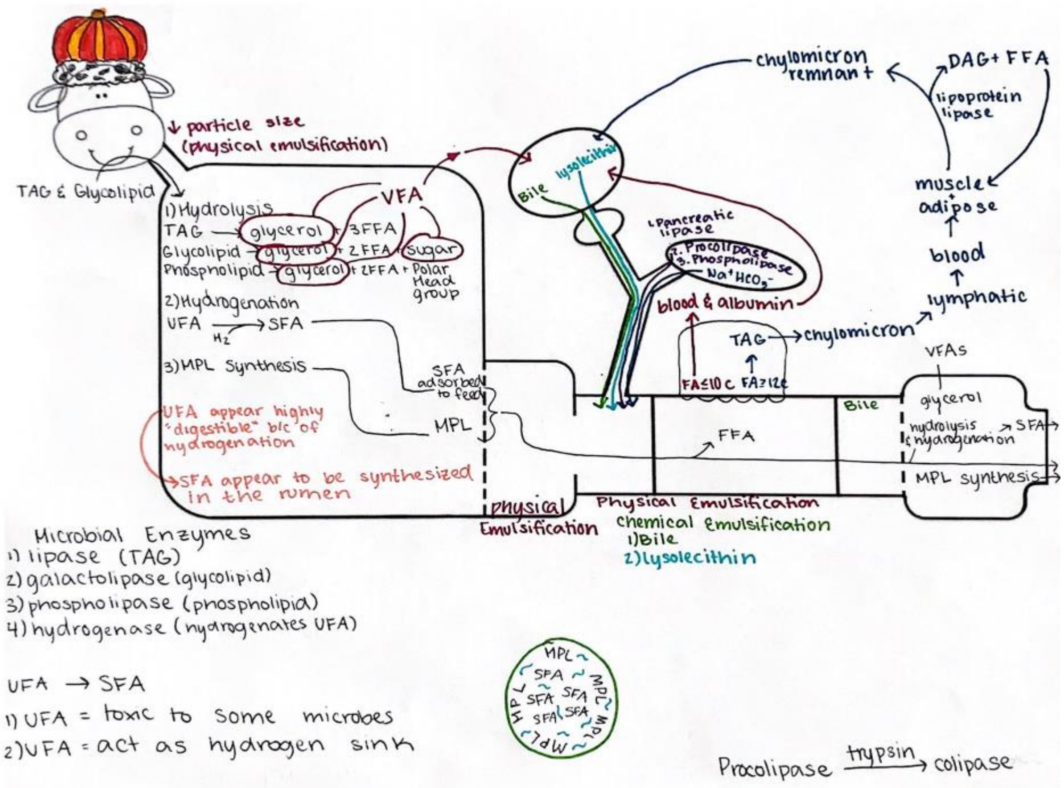
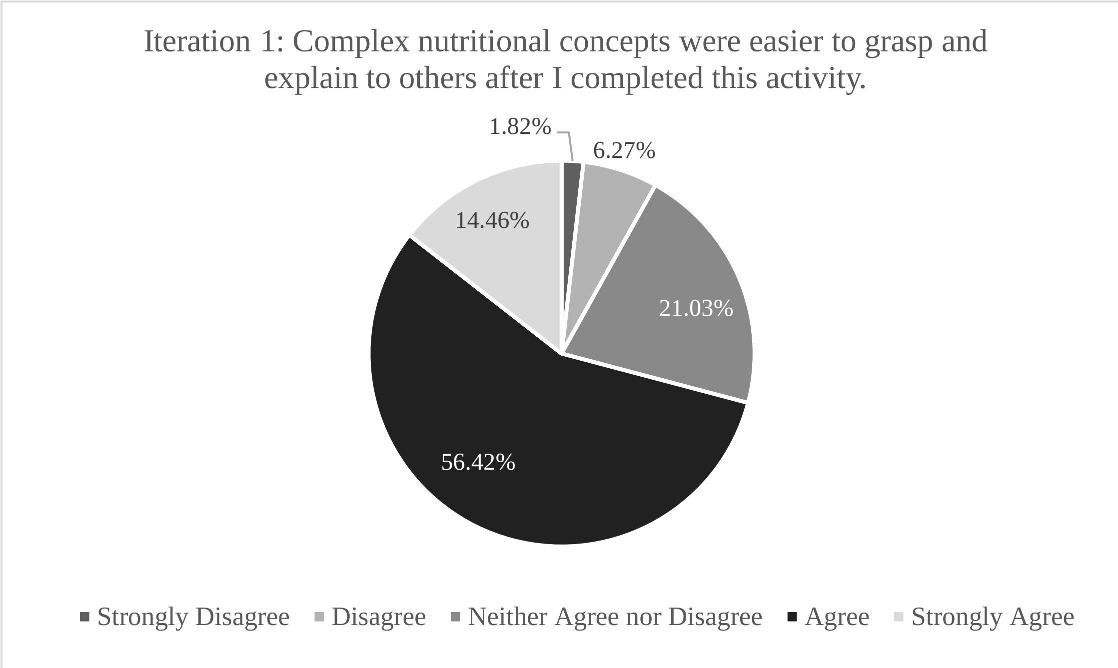


Figure III.4 Sample diagram of lipid digestion, absorption, and utilization in the ruminant

In the second iteration of this learning activity 77.6% of respondents either "Agreed" or "Strongly Agreed" that complex nutritional concepts were easier to grasp and explain to others after they completed this activity (Figure III.5), while 70.4% believe that they will retain the information from this learning activity beyond the next exam (Figure III.6), increases of 6.9% ($P < 0.001$) and 11.4% ($P < 0.001$) respectively over drawing alone without the written component of the assignment. Approximately 20.6% of students neither agreed nor disagreed that they would retain the information from the learning activity beyond the next exam, while 8.9% felt that they would not retain this knowledge in the future. Completing the learning activity helped 87.4% of students to integrate and apply concepts covered in class (Figure III.7) an increase of 9.4% ($P < 0.001$) over drawing diagrams alone as in the first iteration of this activity. Approximately 88.1% of students indicated that the learning activity made it easier to compare concepts learned for one animal with another (Figure III.8), which was not different from iteration 1 ($P = 0.58$). While 62.3% of students agreed or strongly agreed that the learning activity was a helpful study aid for the exam (Figure III.9), 23.7% neither agreed nor disagreed, while 13.9% either disagreed or strongly disagreed with this statement, an increase in disagreement of 6.5% from iteration 1 ($P < 0.001$). Although students indicated that learning was enhanced through drawing and creating a written explanation of their drawings, only 20.1% indicated that they would use a similar method to study in other classes (Figure III.10) compared to 35.3% when asked about drawing the diagrams alone ($P < 0.001$).



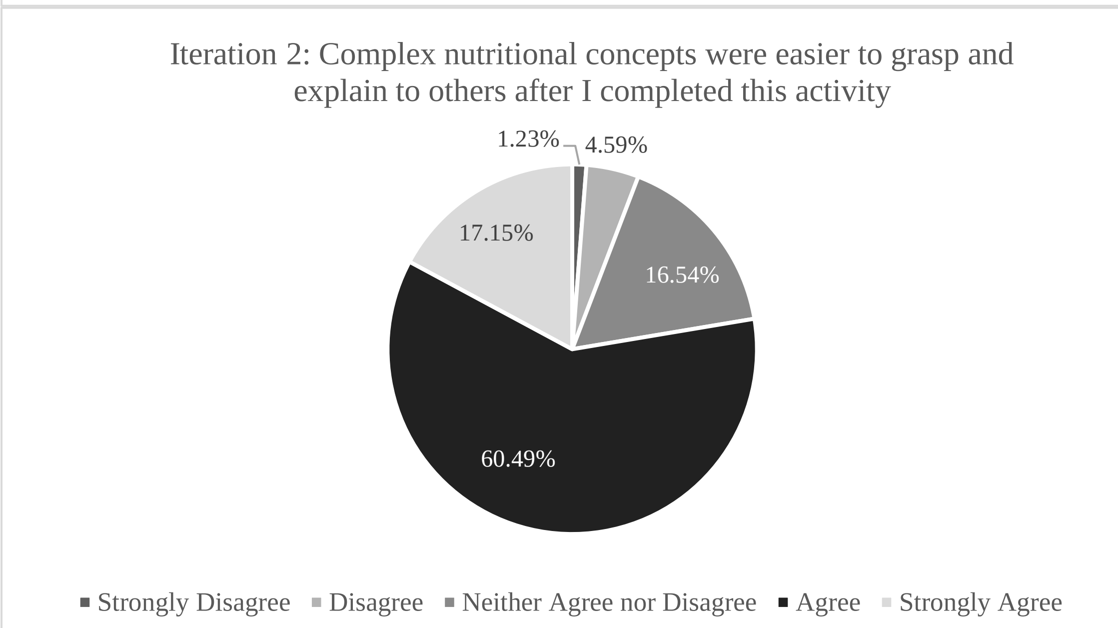


Figure III.5 Likert scale responses to the prompt, “Complex nutritional concepts were easier to grasp and explain to others after I completed this activity” in iteration 1 and iteration 2.

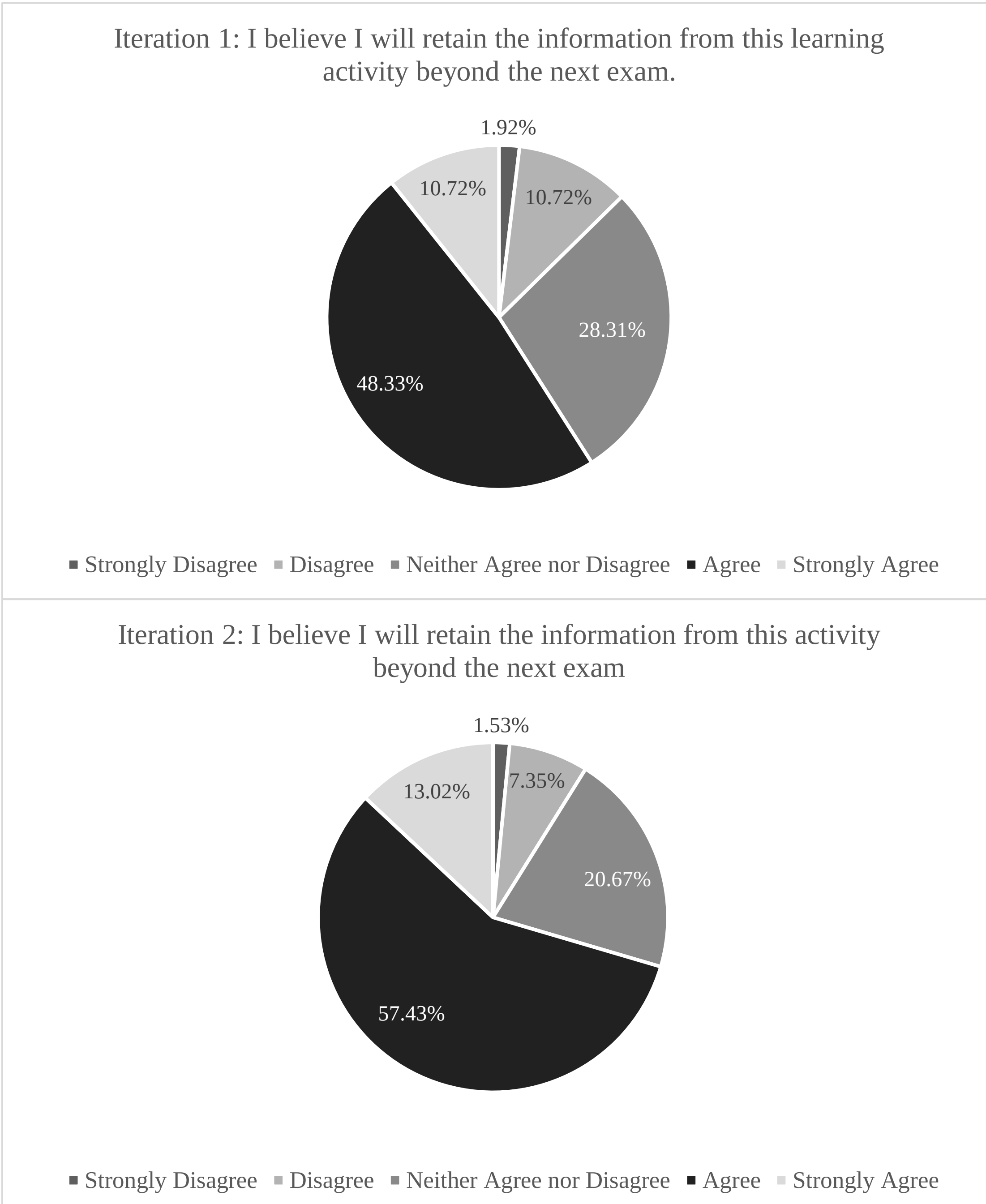


Figure III.6 Likert scale responses to the prompt, "I believe I will retain the information from this activity beyond the next exam" in iteration 1 and iteration 2.

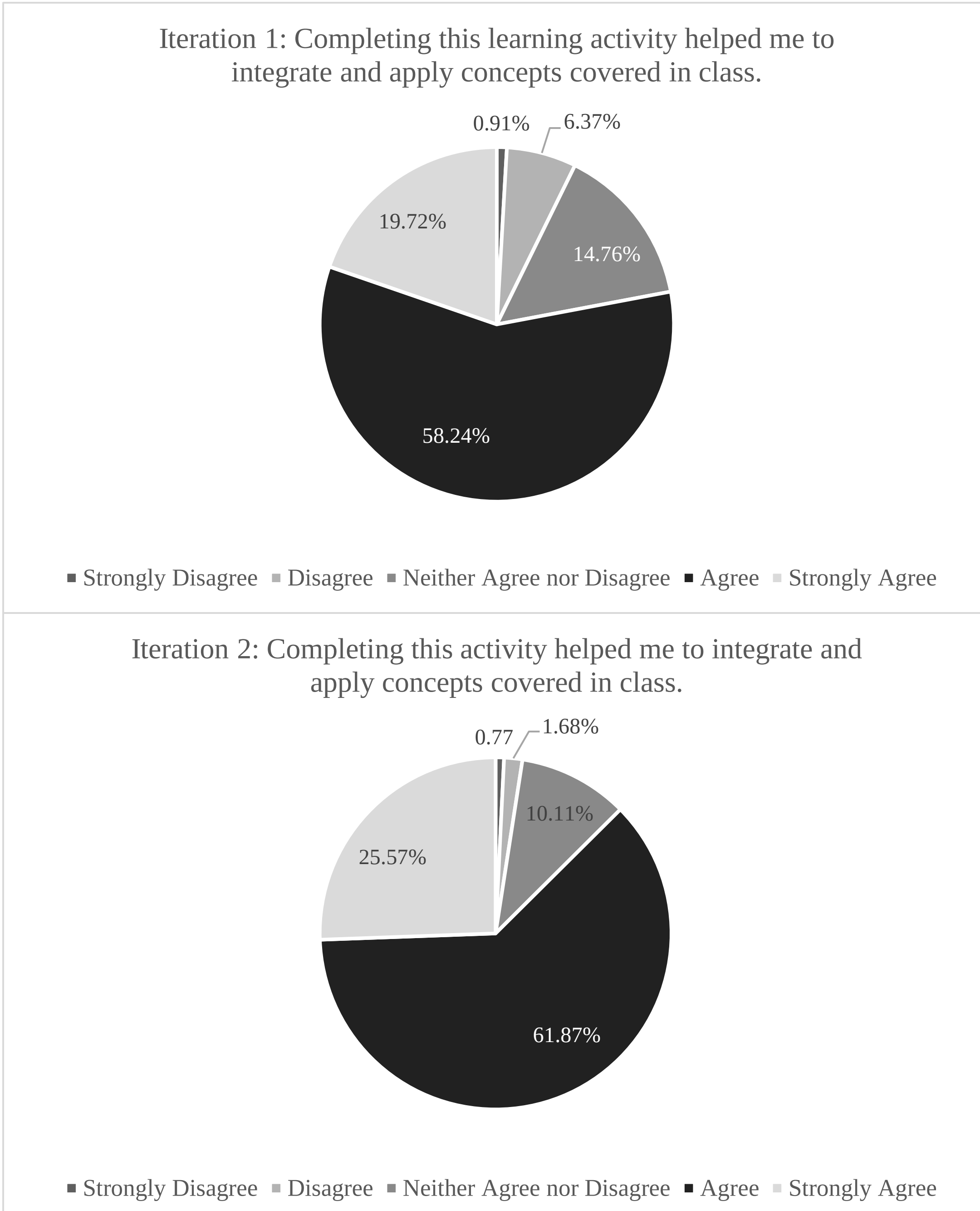


Figure III.7 Likert scale responses to the prompt, "Completing this activity helped me to integrate and apply concepts covered in class" in iteration 1 and iteration 2.

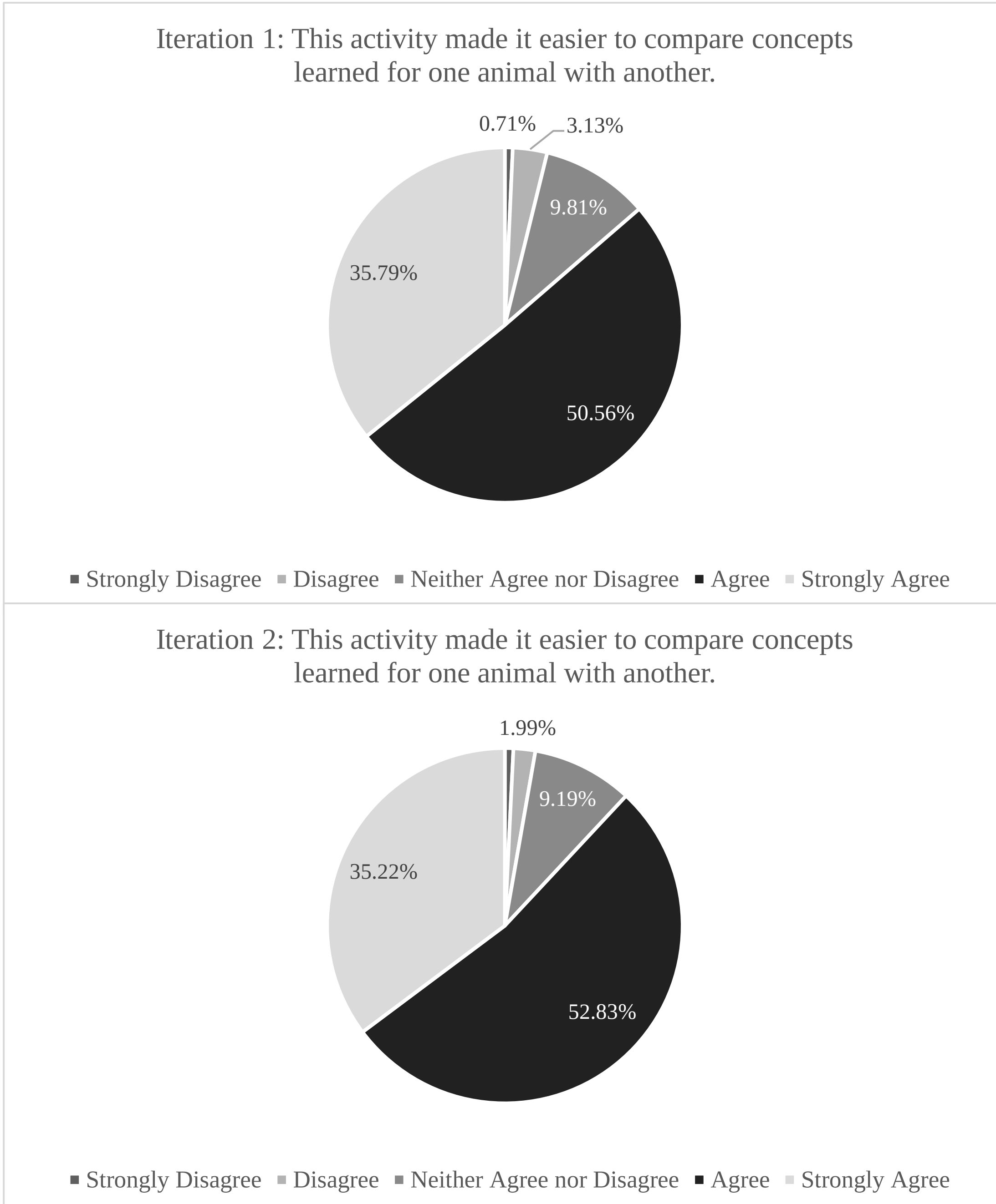


Figure III.8 Likert scale responses to the prompt, “This activity made it easier to compare concepts learned for one animal with another” in iteration 1 and iteration 2.

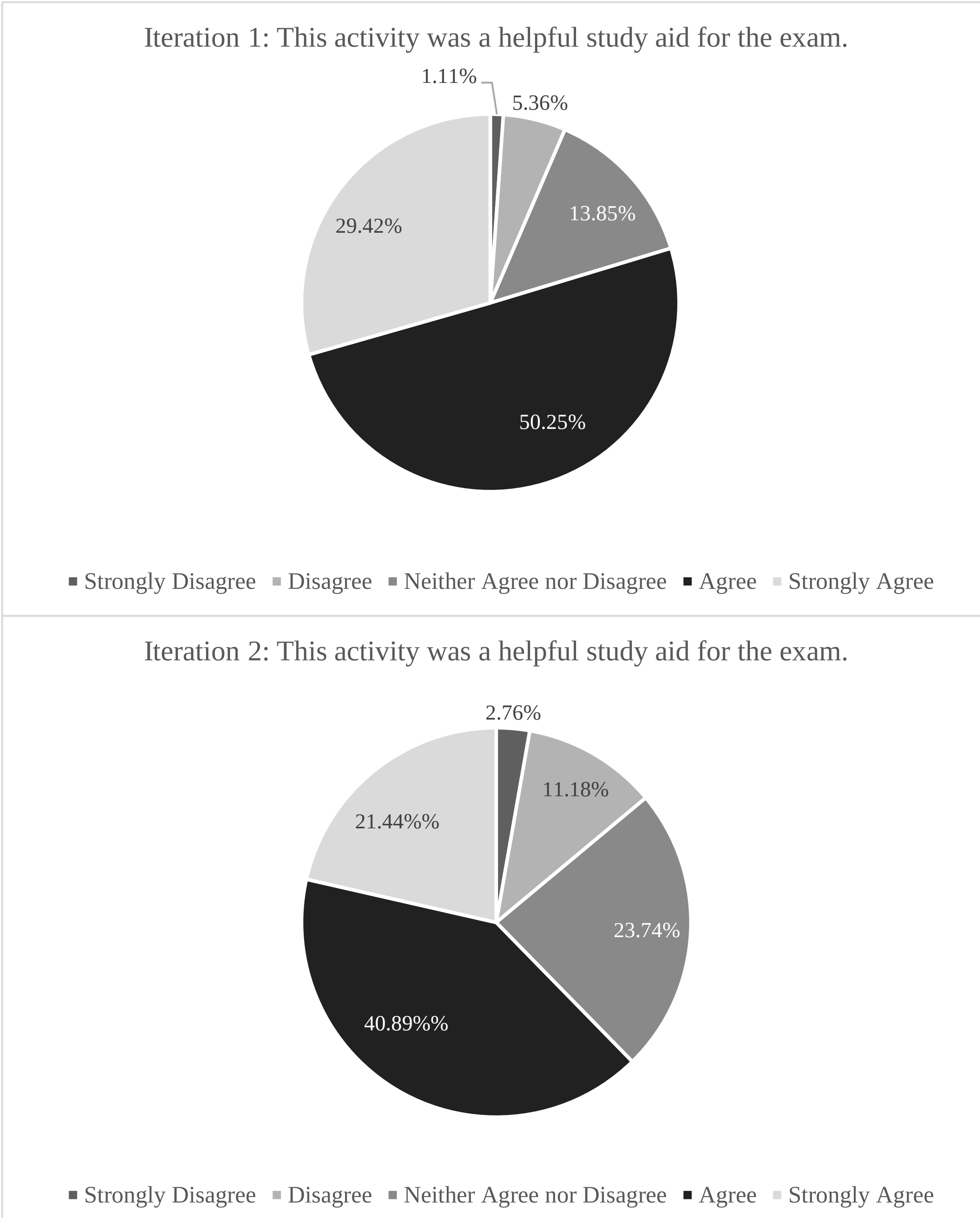


Figure III.9 Likert scale responses to the prompt, "This activity was a helpful study aid for the exam" in iteration 1 and iteration 2.

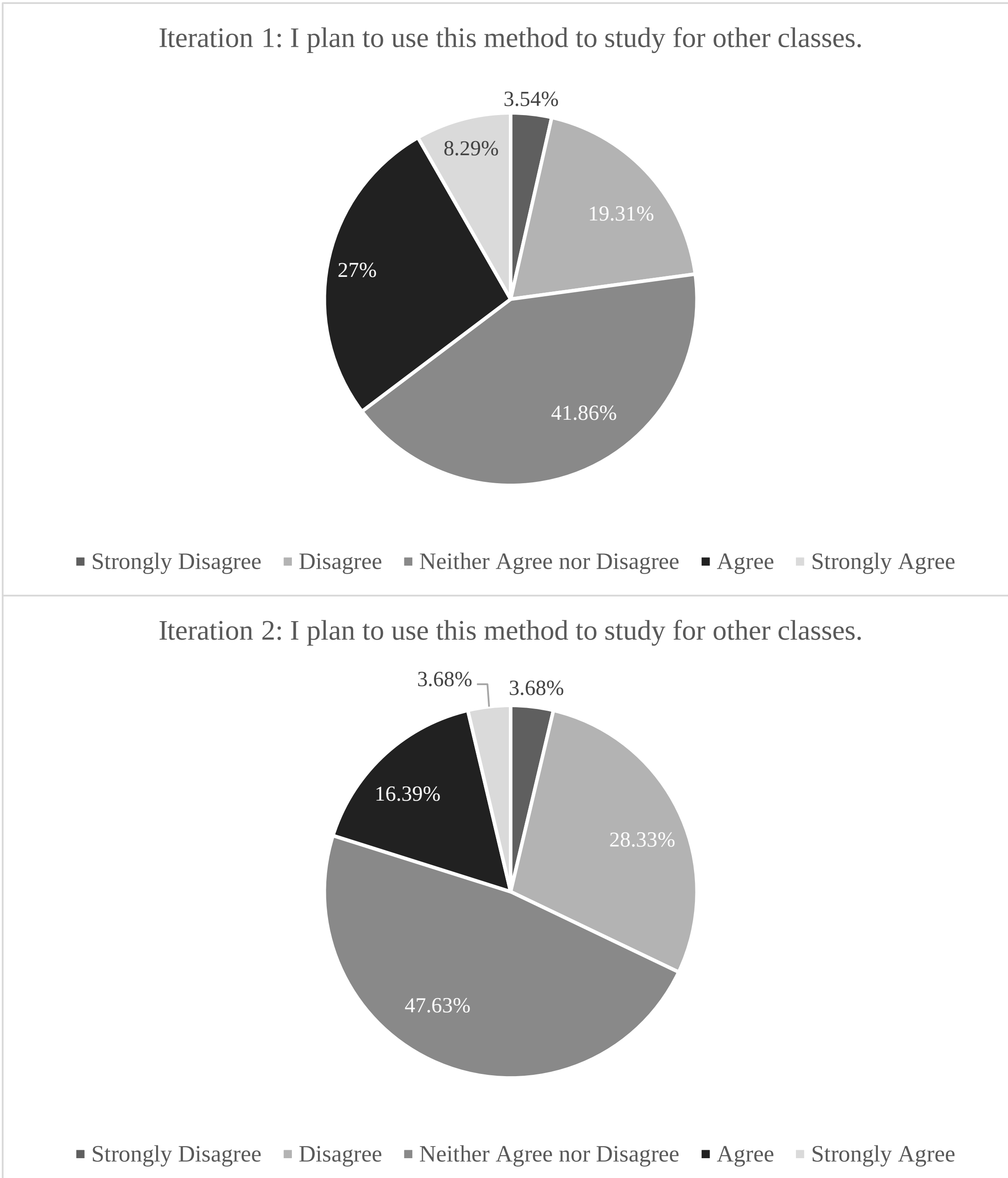


Figure III.10 Likert scale responses to the prompt, "I plan to use this method to study for other classes." in iteration 1 and iteration 2.

Students reported that comparing and contrasting metabolism between the species worked well in this learning activity (35.2%) as drawing diagrams and writing about metabolism of nutrients within the given species helped them to organize and understand their notes (8.9%), visualize the process of metabolism (15.7%), and integrate information to generate inferences (Table III.2).

Table III.2 Frequencies of students' individual response statements by prompt and responses regarding activity design implementation for iteration 2

Prompt and Response	Frequency Total	Total %[a]
What aspects of this learning activity worked well?		
Comparing and contrasting animals	103	35.2
Drawing diagrams helped visualize process of metabolism	46	15.7
Helped to organize and understand notes	26	8.9
Helped to integrate information, make inferences	24	8.2
Made me think about processes thoroughly	21	7.2
Useful as a study aid	17	5.8
Peer review helpful	14	4.8
Benefitted from writing in own words	8	2.7
Describing drawing helped to create self-explanations	8	2.7
Choice of prompts increased interest	6	2.1
Highlighting important parts of drawing	5	1.7
Made me reflect on class notes	5	1.7
Improved my writing skills	4	1.4
Specific formatting, rubric helped with organization	2	0.7
**Item response total*	*293*	
What aspects of this learning activity failed?		
Peer review	56	28.9
None	29	15.0
Redrawing diagrams	23	11.9
Not an exact correlation with exam	12	6.2
Desire more formatting rules	10	5.2
Writing about benefits and limitations	9	4.6
Grammatical rules	9	4.6
Comparisons were difficult	7	3.6
Highlighting important information was tedious	6	3.1
Desire more specific prompts	6	3.1
Repetition	6	3.1

Table III.2 Frequencies of students' individual response statements by prompt and responses regarding activity design implementation for iteration 2, continued

Prompt and Response	Frequency Total	Total %[a]
What aspects of this learning activity failed?		
Would like to compare 3 animals rather than 2	5	2.6
Prompt too specific, difficult, tedious	4	2.1
Grading is too difficult	4	2.1
Writing portion not helpful	3	1.6
Narrowing down important information was difficult	3	1.6
More information needed in class	2	1.0
Item response total	*194*	
What design changes should be made to the learning activity for future iterations?		
None	57	30.7
Clearer instructions, rubric	30	16.2
Peer grade a smaller component	24	12.9
Allow longer papers	14	7.5
More specific prompts	8	4.3
Less emphasis on grammar	7	3.8
Allow more topic options, less strict formatting	6	3.2
Provide examples or outline	6	3.2
Remove drawing component, count drawing less	5	2.7
Require more papers	5	2.7
Ability to report poor peer reviews	5	2.7
Require all 3 species rather than 2	4	2.2
Allow more time to complete writing portion	4	2.2
Match topics to exam questions	4	2.2
Do not require highlighting important information on drawings	3	1.6
Provide extra credit for additional peer reviews	2	1.1
Do not include writing component	2	1.1
Item response total	*186*	
How has this activity impacted your learning or study methods?		
Improved understanding of material	50	16.8
Helped to rewrite, verbalize notes in own words	43	14.4
Integration of concepts	21	7.1
Did not help	19	6.4
Made comparison easier	18	6.0
Drawing reinforced information	15	5.0
Helped me see the big picture	15	5.0
Helpful, no explanation	13	4.4

Table III.2 Frequencies of students' individual response statements by prompt and responses regarding activity design implementation for iteration 2, continued

Prompt and Response	Frequency Total	Total %[a]
How has this activity impacted your learning or study methods?		
Improved retention	10	3.4
Forced me to look at details	9	3.0
Made me reflect on my knowledge	9	3.0
Improved my communication skills	8	2.7
I will draw in other classes as a study, learning method	8	2.7
Reduced the amount of study needed	7	2.4
Forced me to study	6	2.0
Improved my grades	4	1.3
Helped me to keep up in class	4	1.3
Helped my understand application of material	4	1.3
Improved confidence in topics	3	1.0
I was able to utilize other students' understanding	3	1.0
Improved my writing skills	3	1.0
Challenging in a good way	2	0.7
Item response total	*298*	

Note. Individual responses to prompts were clustered into categories by theme, counts were made.
[a] Percent totals were calculated by taking the response statement count and dividing by the total individual responses for the prompt in question.
*Item response total does not match number of students (n=301) as student responses may fall into more than 1 category, or they did not respond to the prompt.

Although 4.8% of students indicated that they found peer review to be helpful, 28.9% of students identified the process of peer review as problematic, especially when assigning grades. Approximately 30.7% of students suggested that no changes should be made to the learning activity in the future. However, 16.2% suggested more detailed instructions and rubrics be provided, and 12.9% desired that peer review make up a smaller component of their grade for the assignment. Several students (7.5%) also wished for longer allowances in paragraphs and word count for their papers, as they found it difficult to narrow down important information (1.6%) about their topic. Students indicated that completing learning activities consisting of both a writing component in and drawing diagrams of nutrient digestion helped to improve their understanding of course material (16.8%), verbalize notes in their own words (14.4%), and integrate concepts (7.1%) from within the class and other courses to increase understanding of course material. About 6.4% of students did not find this learning activity helpful at all.

Discussion

Asking students to create rather than interpret visual models has been shown to increase comprehension and retention of information and facilitate more effective recall (Beveridge and Parkins, 1987; Gobert and Clement, 1999; Van Meter and Garner, 2005; Ainsworth, 2010). Indeed, from a constructionist standpoint in which learning is defined as construction of meaning through construction of knowledge artifacts, creating ones' own visual model is a vital part of the learning process (Papert, 1993). In accordance with these findings, we found that drawing to learn was an effective pedagogical strategy in our Principles of Animal Nutrition course. Creating diagrams of digestion and utilization of nutrients helped students to fill in gaps in their understanding and organize their knowledge to increase retention and integration of new concepts (Ainsworth and Th Loizou, 2003; Ainsworth, 2010).

"I also found that after doing the redrawing activities, when I went back to review my notes, so many things started to connect the dots. It made me realize how much applying the notes to the drawing really made a difference."

Additionally, in agreement with Köse (2008), students were able to identify areas of confusion or misconception through drawing which enabled them to address these disparities before they were formally assessed.

"I really liked that the diagrams summarized everything, so that as I was working on them, I could easily recognize the things I didn't quite understand and use my more in-depth notes to understand them."

In keeping with these findings, Stenning and Oberlander (1995) suggest that visual models limit the amount of potential abstraction and force the learner to confront incomplete comprehension of concepts that they may be able to camouflage from themselves when generating written explanations.

Creating their own diagrams to represent the processes of digestion, absorption, and utilization of nutrients gave students in this course confidence in their abilities to both understand and explain complex nutritional concepts to others. Constructing visual models takes advantage of inferences like spatiality to communicate more directly than verbal explanations when it comes to explaining processes (Bobek and Tversky, 2016). Learning requires building from existing knowledge scaffolding and making connections between what is known and new knowledge to construct meaning (Reynolds et al., 2012). Drawing diagrams of nutrient digestion, absorption and utilization helped students to organize, integrate, and apply their knowledge effectively in this course similar to observations made by Quillin and Thomas (2015).

"The drawings, and the comparison between the animals were the most helpful to me because my brain was able to categorize the information easily."

Additionally, through creating visual models, students were able to more readily visualize the ways in which structure and function of digestive and accessory organs or enzymes are linked, as well as the similarities and differences between species.

"Going through the processes of each individual species was helpful in determining similarities and differences between them. Also, seeing the processes drawn out were very helpful in understanding how each of them worked and which organ it affected."

Often complex systems or processes are difficult for students to grasp through purely verbal instruction. Developing visual models is an useful method to increase understanding of interactions within these complex systems allowing learners to more readily generate inferences or make comparisons (Bobek and Tversky, 2016). Teaching students to create visual models of complex systems or processes moves them from a memorization approach to true understanding of the concept or interactions within the system (Luckie et al., 2011). Additionally, learning and solving problems from visual models requires less cognitive effort than from text as the visual representation of an abstraction can benefit from spatial or relational inferences in a way that text cannot (Larkin and Simon, 1987; Zhang and Norman, 1994; Cox, 1999; Ainsworth and Th Loizou, 2003).

"Because they concisely illustrated the entire digestion processes we covered, [creating the diagrams] allowed us to see how certain interactions were occurring in sequence, which then helped better understand end products and utilization."

Drawing to learn helped students to develop self-explanations of concepts learned in class, using the diagrams to tell a story rather than memorizing facts about digestion which in turn increased understanding of the processes of nutrient digestion and utilization in the species studied.

"The learning activities helped me to understand the concepts in class by showing me the overall story of how things are processed in the animals. Once I understood the story and was able to explain it to someone, it helped me understand the concepts better".

Creating self-explanations or a "story" to explain complex concepts and interactions has been demonstrated to deepen understanding, allowing students to generate inferences, and more effectively scaffold future information (Chi et al., 1994; Ainsworth and Th Loizou, 2003).

While constructing diagrams of digestive processes increased student comprehension and their ability to apply and compare concepts during the first iteration of this project, we found that adding a writing component to the assignment increased the effectiveness of the learning activity. Writing to learn is widely recognized as an effective pedagogical tool to help students to develop understanding of scientific concepts and processes and promote critical thinking (Thaiss and Zawacki, 2006; Reynolds et al., 2012; Finkenstaedt-Quinn et al., 2021). However, writing to learn is underutilized as a teaching strategy in STEM courses (Reynolds et al., 2012). Often instructors cite class size, time, and effort required to provide useful feedback as barriers to the implementation of writing assignments to a substantial degree in STEM courses (Finkenstaedt-Quinn et al., 2021). We chose to mitigate these issues through the use of peer review. Finkenstaedt-Quinn et al. (2021) reported that peer review of writing assignments in STEM disciplines where the focus is increasing conceptual knowledge, rather than writing skills, can help students to develop their knowledge through the process of metacognition and peer instruction. As students read and provide feedback on their classmates' work, they engage in metacognitive evaluation of their own work and learn through teaching others. Reviewing their classmates' work exposes students to new methods of approaching or explaining the topic which can improve their understanding of the concepts or can provide a form of self-evaluation as they consider the accuracy of the explanation and the manner in which it is presented (Pelaez, 2001). Although peer review has been shown to improve understanding and performance in STEM courses, the procedures for peer review must be effectively scaffolded to ensure that feedback is substantive and helpful (Finkenstaedt-Quinn et al., 2021). As 28.9% of students identified the process of peer review as problematic in this learning activity it is clear greater scaffolding of the process is required. In future iterations of these learning activities, we will provide a practice peer review assignment with feedback as well as more detailed instructions to the reviewer to increase the efficacy of peer review to provide peer instruction that can truly supplement learning.

We found that including aspects of both verbal and visual explanations was most effective in supporting learning in the nutritional physiology classroom in accordance with Aleven and Koedinger (2002). Cox (1999) also suggests that the process of translating across modalities from linguistic or verbal explanations to a visual or diagrammatic representation and back may be more effective in supporting self-explanations and learning among students than using a single modality. When students were asked to both create diagrams of nutrient digestion, absorption, and utilization and then use their diagrams to generate a written explanation of those processes, comparing and contrasting across species or nutrients, they reported more effective retention of information, integration and application of their knowledge, and confidence in understanding complex nutritional concepts and teaching them to others. Developing visual models helped students to focus on connections and creating written explanations helped to refine connections between concepts and elements within the diagram (Bobek and Tversky, 2016). Understanding of both the visual models and verbal information were enhanced through translating across modalities from verbal to visual and back again (Craik and Lockhart, 1972; Ainsworth et al., 2002).

"It was most helpful to have to explain the processes from start to finish. I also think this helped most when coupled with redrawing the animal diagrams. It really made me think about what each thing written meant and how it impacted the system."

"I really liked including the drawings with the papers…pairing the two together really helped me write the paper. I also liked the design of the papers. I like that they were used as comparisons as that really helped me better understand the material."

As students construct meaning using their own knowledge and integrating new information, both drawing and writing help students to make connections among items within a system and develop their own self-explanations (Reynolds et al., 2012). Creating visual models of abstract ideas or complex concepts helps to make the imperceptible visible while generating written explanations of their drawings requires students to articulate their thought processes and make direct comparisons using their diagrams. Discontinuing the visual modeling portion of the assignment would likely have detrimental effects on comprehension, knowledge retention, and integration of information as writing alone can be less effective than drawing when creating self-explanations as reported by Paoletti (2005) and Ainsworth and Th Loizou (2003). By using both a linguistic and visual approach concurrently, learners benefit from the synergistic properties of each modality in accordance with dual coding theory (Paivio, 1990; Clark and Paivio, 1991; Paivio and Clark, 2006). Paivio (1990) theorized that cognition is enhanced through activating both the verbal and visual systems by which information is categorized, stored, and integrated. In this way, learning through drawing diagrams is supported through verbal explanations that ask learners to actively process the material to reflect their understanding and draw conclusions (Ainsworth, 2010). Translating across modalities encourages learners to interact with both their external and internal models to construct self-explanations which are used in scaffolding knowledge and construction of meaning (Zhang and Norman, 1994; Cox, 1999; Paivio and Clark, 2006). By adding a written component to this drawing assignment, students are encouraged to manipulate the mental model they have constructed in tandem with their external model of digestion to solve problems and make inferences across species in response to the written prompts (Cox, 1999). Students indicated that they were unlikely to employ similar methods for studying in other courses and felt that incorporating both written and drawn portions of the assignment did not prepare them as well as they were hoping for the exam. However, they did indicate that the assignment increased their learning so their reluctance to use this method in the future is likely due to the great effort required to create both visual models of course concepts and writing a written explanation rather than ineffectiveness of the approach. Additionally, exam questions should more closely relate to the learning activity to increase its utility as a study aid in future semesters.

Conclusion

Creating diagrammatic representation of nutrient digestion, absorption, and utilization across livestock species effectively increased student comprehension, confidence, and ability to integrate and apply information from the course. While drawing these diagrams did improve student outcomes, adding a writing component to the drawing assignment increased its effectiveness. When students were required to both create a visual model of digestion and then use it to support their written explanation and comparisons across species, their confidence and proficiency in retaining and explaining complex nutritional concepts and making inferences across species increased. Incorporation of similar learning activities in accordance with dual coding theory that include both creating visual models and written explanations will likely be effective in enhancing student learning in other biological science or physiology courses. Future research should focus on degrees of scaffolding with gradual release in similar activities to increase student agency by allowing them to create novel personalized visual models and determine the effect of such an approach on learning and comprehension.

References

Ainsworth, S. 2010. Improving learning by drawing. In: Proceedings of the 9th International Conference of the Learning Sciences-Volume 2. p 167-168.

Ainsworth, S., P. Bibby, and D. Wood. 2002. Examining the effects of different multiple representational systems in learning primary mathematics. The Journal of the Learning Sciences 11(1):25-61.

Ainsworth, S., V. Prain, and R. Tytler. 2011. Drawing to learn in science. Science 333(6046):1096-1097.

Ainsworth, S., and A. Th Loizou. 2003. The effects of self-explaining when learning with text or diagrams. Cognitive science 27(4):669-681.

Aleven, V. A., and K. R. Koedinger. 2002. An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. Cognitive science 26(2):147-179.

American Association for the Advancement of Science. 2011. Vision and change in undergraduate biology education: A call to action. Washington, DC

Arneson, J. B., and E. G. Offerdahl. 2018. Visual literacy in Bloom: Using Bloom's taxonomy to support visual learning skills. CBE—Life Sciences Education 17(1):ar7.

Beveridge, M., and E. Parkins. 1987. Visual representation in analogical problem solving. Memory & Cognition 15(3):230-237.

Bobek, E., and B. Tversky. 2016. Creating visual explanations improves learning. Cognitive research: principles and implications 1(1):1-14.

Chi, M. T. 1997. Quantifying qualitative analyses of verbal data: A practical guide. The journal of the learning sciences 6(3):271-315.

Chi, M. T., N. De Leeuw, M.-H. Chiu, and C. LaVancher. 1994. Eliciting self-explanations improves understanding. Cognitive science 18(3):439-477.

Clark, J. M., and A. Paivio. 1991. Dual coding theory and education. Educational psychology review 3(3):149-210.

Collins, A. 1999. The changing infrastructure of education research. Issues in education research:289-298.

Cox, R. 1999. Representation construction, externalised cognition and individual differences. Learning and instruction 9(4):343-363.

Craik, F. I., and R. S. Lockhart. 1972. Levels of processing: A framework for memory research. Journal of verbal learning and verbal behavior 11(6):671-684.

Damyanov, I., and N. Tsankov. 2018. The role of infographics for the development of skills for cognitive modeling in education. International Journal of Emerging Technologies in Learning (iJET) 13(1):82-92.

Design-Based Research Collective. 2003. Design-based research: An emerging paradigm for educational inquiry. Educational researcher 32(1):5-8.

Finkenstaedt-Quinn, S. A., N. Polakowski, B. Gunderson, G. V. Shultz, and A. R. Gere. 2021. Utilizing Peer Review and Revision in STEM to Support the Development of Conceptual Knowledge Through Writing. Written Communication:07410883211006038.

Gobert, J. D., and J. J. Clement. 1999. Effects of student-generated diagrams versus student-generated summaries on conceptual understanding of causal and dynamic knowledge in plate tectonics. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching 36(1):39-53.

Jonassen, D., J. Strobel, and J. Gottdenker. 2005. Model building for conceptual change. Interactive Learning Environments 13(1-2):15-37.

Köse, S. 2008. Diagnosing student misconceptions: Using drawings as a research method. World Applied Sciences Journal 3(2):283-293.

Larkin, J. H., and H. A. Simon. 1987. Why a diagram is (sometimes) worth ten thousand words. Cognitive science 11(1):65-100.

Luckie, D., S. H. Harrison, and D. Ebert-May. 2011. Model-based reasoning: using visual tools to reveal student learning. Advances in Physiology Education 35(1):59-67.

Michael, J. 2007. What makes physiology hard for students to learn? Results of a faculty survey. Advances in physiology education 31(1):34-40.

National Research Council. 2012. Discipline-based education research: Understanding and improving learning in undergraduate science and engineering. National Academies Press.

Nersessian, N. J. 1999. Model-based reasoning in conceptual change, Model-based reasoning in scientific discovery. Springer. p. 5-22.

Paivio, A. 1990. Mental representations: A dual coding approach. Oxford University Press.

Paivio, A., and J. Clark. 2006. Dual coding theory and education. In: Draft chapter presented at the conference on Pathways to Literacy Achievement for High Poverty Children at The University of Michigan School of Education

Paoletti, G. 2005. Writing-to-learn and graph-drawing as aids of the integration of text and graphs, Effective Learning and Teaching of Writing. Springer. p. 587-597.

Papert, S. 1993. The children's machine: Rethinking school in the age of the computer. ERIC.

Pelaez, N. J. 2001. Calibrated peer review in general education undergraduate human physiology. In: Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science, Costa Mesa, CA. p 1518-1530.

Quillin, K., and S. Thomas. 2015. Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. CBE—Life Sciences Education 14(1):es2.

Reynolds, J. A., C. Thaiss, W. Katkin, and R. J. Thompson Jr. 2012. Writing-to-learn in undergraduate science education: a community-based, conceptually driven approach. CBE—Life Sciences Education 11(1):17-25.

Stenning, K., and J. Oberlander. 1995. A cognitive theory of graphical and linguistic reasoning: Logic and implementation. Cognitive science 19(1):97-140.

Thaiss, C. J., and T. M. Zawacki. 2006. Engaged writers and dynamic disciplines: Research on the academic writing life. Boynton/Cook Portsmouth, NH.

Van Meter, P., and J. Garner. 2005. The promise and practice of learner-generated drawing: Literature review and synthesis. Educational Psychology Review 17(4):285-325.

Wilson, T. E., and K. E. Barrett. 2021. Gastrointestinal jabberwocky to bioengineering design: using function diagrams to teach physiology. Advances in Physiology Education 45(2):264-268.

Zhang, J., and D. A. Norman. 1994. Representations in distributed cognitive tasks. Cognitive science 18(1):87-122.

CHAPTER IV

DEVELOPING A STUDENT-CREATED DIGITAL REFERENCE IN FOOD MICROBIOLOGY GROUNDED IN CONSTRUCTIVIST AND CONSTRUCTIONIST LEARNING THEORY: A DESIGN-BASED RESEARCH TRIAL

Synopsis

Within STEM disciplines an instructionist conceptualization and approach to teaching and learning is prevalent. This conceptualization gives rise to traditional practices in teaching that promote a transfer/acquisition approach to learning where students are consumers of information rather than participants in knowledge creation. We seek to offer an alternative approach to teaching and learning in food microbiology through creation of a student-developed digital reference based on design principles derived from the constructionist and constructivist theories of teaching and learning, where learners are situated as designers and creators of knowledge. Over the course of a semester, students collaboratively constructed a section of a food microbiology textbook in their own vernacular. This reference will be used as an evolving course resource for future classes. Transformation of information to create an artifact with real-world utility promotes a conceptualization of knowledge and learning as continuously constructed rather than finite, promoting learner agency. A design-based research study was conducted to implement this project in an upper-level food microbiology course over multiple iterations. Students completed the project, and their voices and experiences were an integral aspect of the design and iteration process. Design changes will be implemented in future semesters based on student feedback and instructor observations.

Findings from this study indicate that constructionist learning theory benefits from design principles and concepts originating in social constructivism, specifically the ideas of co-construction of knowledge and scaffolding. Learning principles applied in the design and implementation of this project extend beyond the field of food microbiology and may be applied to any number of disciplines.

Introduction

Within STEM disciplines there is a prevalence of an instructionist conceptualization and approach to teaching and learning. Instructors and students alike view learning as accumulation of information which can impede deeper understanding and higher-order thinking (Papert and Harel, 1991). An instructionist conceptualization of learning gives rise to traditional practices in teaching that promote a transfer/acquisition approach to learning where students are consumers of information rather than active participants in knowledge creation (Donaldson, 2019). Within the food microbiology discipline there exists an additional challenge in that undergraduate students often come from a variety of backgrounds and majors such as animal science, biomedical science, nutrition, or agricultural science. These students may not know how to connect with the material presented in class because they lack general background knowledge, vested interest in course content, or fail to see how the subject directly applies to their chosen field. Our goal is to build a process for the creation of a resource for students that will bridge the gap between their areas of interest and course material. We seek to offer an alternative approach to teaching and learning in food microbiology through creation of a student-developed digital reference. Development of this reference is based on design principles derived from the constructionist and constructivist theories of teaching and learning where learners are situated as designers, promoting learner agency. We describe our efforts to build a process for the construction of a student-created digital textbook in a large-enrollment science course and the implication of this project on constructionist and constructivist theories of teaching and learning.

The constructivist theory of teaching and learning provided the basis for the design of this project. Constructivist theory defines learning as not the acquisition of information, but the active construction of knowledge and meaning (Piaget and Cook, 1952; Piaget, 1977). Cognitive constructivism describes learning as an individual and internal process where meaning is constructed through transformation of information into knowledge (Piaget and Cook, 1952). The introduction of social constructivism by Vygotsky (1980) contributed to the theory of constructivism by reframing learning as construction of meaning through social negotiation and co-construction of knowledge mediated by sociohistorical and linguistic context.

Constructionist theory has its basis in cognitive constructivism and expands on its definition stating that construction of observable artifacts that exemplify knowledge being constructed will create a positive feedback loop whereby construction of the artifact promotes construction of knowledge, contributing to further artifact development in a continuous cycle (Stager, 2005). Constructionist theory promotes learner agency by allowing students authority over artifact development, creating personal significance and feelings of ownership (Kafai, 2005; Blikstein, 2008). According to this theory, learning occurs most powerfully when a student creates something of their own design with “real-world” significance. Indeed, the knowledge that peers and instructors will view their work adds value and meaning to the construction of knowledge and the artifact, thereby increasing engagement with the course and feelings of belonging within the classroom community (Sinatra et al., 2015). Therefore, the goal of this study is to determine *what* *design features are needed to promote constructivist and constructionist learning in a microbiology classroom?*

All procedures and data collection were approved by the Texas A&M University Institutional Review Board, IRB2020-0983M, and students provided informed consent for the use of their data.

Methods

This is a design case study grounded in design-based research methodology (Hoadley, 2004). We have adopted a design-based approach to this project to allow for improvements in project design over multiple semesters and to contribute to learning theories on which the study was grounded. Within design-based research, interventions and theories of teaching and learning are interwoven and examined through a cycle of design, analysis, and refinement that is repeated over multiple iterations. This cycle begins by grounding the intervention design in learning theory and seeks to generate findings which speak to the theory on which the innovation was predicated (Sandoval and Bell, 2004). This process helps to generate practices that are both theoretically sound and functional within a practical setting. Design-based research can be used to further understanding of relationships between context of learning, design of innovation, learning theory, and artifacts. Flexibility facilitated by design-based research allows for the incorporation of unexpected outcomes and evaluation of emerging themes and new lines of inquiry should they arise (Design-Based Research Collective, 2003). This study reports findings of the first 2 iterations of a larger design-based study which will continue over several more iterations.

All procedures and data collection were approved by the Texas A&M University Institutional Review Board, IRB2020-0983M, and students provided informed consent for the use of their data.

Project Design

To ground our design in theory, the first iteration was developed based on design principles derived from *constructivist* theory 1) learners use information as raw materials for the construction of knowledge 2) knowledge is co-constructed through social negotiation. Design principles were also derived from *constructionist* theory 3) facilitating development of learner agency, 4) learners transform information into knowledge and knowledge artifacts with a real-world audience, and 5) making involves tinkering and exploration. These design principles were translated into the structure of the learning experience.

Students engaged in collaborative construction of a digital reference in food microbiology to be used as a course resource by future students. This reference resembles a traditional textbook design but allows students creative license to present information in the manner they deem most effective or engaging, with the potential for this reference to replace the course textbook in the future. In this way, students are no longer acquiring knowledge, but generating it.

During the first iteration of this design-based project, students were invited to volunteer to participate in a pilot study of the activity for honors credit. These students (n=4) were paired according to topic interests and provided with the complete

Methodology for Building Living Textbook Contribution

1. Choose topic/subtopic (due 9/16/2020)
2. Begin compiling sources: In order to assemble sources, you must be able to differentiate between those that are credible and those that are not.
    a. To assess the credibility of sources, consider the following:
        i. Intended audience and purpose of the resource: i.e. persuasion, marketing, teaching etc.
        ii. Perspective: Is the source obviously biased? If the source is extremely biased and the bias is evident/blatant, it may be misleading or misrepresent information. Many sources hold a slight bias and may be balanced by another source from a different perspective.
        iii. Timeliness: Does your source provide the most recent research or known information about your chosen topic? The scientific world evolves quickly as new discoveries are constantly being made. Citations need to provide recent, state-of-the-art knowledge, and you should seek to balance that against a careful understanding of the historical research that's been significant that has allowed the science to progress to current.
        iv. Authority: does the writer cite their sources or credentials, has the resource been peer-reviewed etc. Websites with urls ending in .edu or .gov are typically more reliable than .com or .org sites.
        v. Relevance: Is the article connected to your chosen topic?
        vi. Source Credibility Video
    b. You must also be able to identify sources that are useful and specifically related to your topic of interest to avoid going down the proverbial rabbit hole of loosely related information. My suggestion would be to create an outline of the sub-topics you find most important to cover and then be sure your sources can directly relate to the sub-topics you have identified. Use the rubric, feedback from classmates and instructor to help to identify areas of greatest importance. And feedback from classmates and instructors. Also, look at the text from existing textbooks; what topics are they covering and discussing. These have been edited and some have stood the test of time.
        i. Helpful links: How to read scholarly articles 1, How to read scholarly articles 2
3. Outline (due date) formatting should be laid out similar to this:
    a. Introduction-brief overview and statement of importance of your topic, why should your readers care?
    b. Information about the topic you have chosen
        i. History
        ii. Impact on society
        iii. Critical factors connected to your topic
        iv. Illustration or multimedia included (YouTube, Canva, Biorender, Piktograph)
        v. Potential solutions
        vi. Identify areas for future study
    c. References cited in **International Journal of Food Microbiology** format
        i. Citation instructions

Figure IV.1. Excerpt from instructions given to students in iteration 1 of the Living Digital Reference Design-Based Research study

instructions for project development (Figure IV.1). Design moves generated by iteration 1 of this project were incorporated into the instructions and resources for iteration 2. Pilot participants met with instructors every 3 weeks to check on their progress.

We structured the learning activity into stages to be completed over 13 weeks. Additional resources were provided to mitigate potential issues. Resources included how to assess source credibility, avoid plagiarism, read a scholarly article, etc. Students were first asked to select a topic from a list identified by the instructor as having great significance to the course. Topic selection was used as a means of grouping students with similar interests. Assigning topics in this manner allows creative license and learner agency while maintaining instructor control over the material being contributed to the reference (Jiake et al., 2010; Galarza et al., 2017a). In the second stage, students watched a video explaining how to assess source credibility before they began to compile their sources. As the students found and evaluated new sources, they were asked to create an outline for their product assimilating those sources into a cohesive structure, similar to a sample outline provided. This afforded students the opportunity to engage in higher order thinking on Bloom's taxonomic scale as they analyzed and evaluated the utility and credibility of potential sources (Anderson and Bloom, 2001).

Students then revised their outline, adding detail and streamlining their ideas. Additional resources provided within this stage included how to read scholarly articles and how to format references in the preferred citation style. After creating an outline of their topic and identifying helpful resources, students began constructing their portion of the digital reference. Students worked collaboratively in groups of three to break down rigorous topics into manageable segments. Collaborative learning activities are based upon the theory that learning is naturally social (Gerlach, 1994), and more effective learning takes place through the exchange of ideas and expertise (Jiake et al., 2010). Additionally, collaboration is an important skill that employers have identified as vital to the workplace (Barron, 2000), and in fact expect students to develop collaborative skills prior to entering the workforce (Coleman, 1999). Thus, it is important to the professional development of students to learn to work productively and efficiently with their peers. Although at times collaborative learning activities may bring about challenges such as unequal levels of investment, logistical issues of managing multiple schedules, or student frustration, regular reflections on team and individual progress and instructor involvement limit these issues (Johnson and Johnson, 1994).

Students worked collaboratively using Google Docs to create the first draft of their product, including text, citations, and any multimedia they wished to include. After completing their first draft, students then participated in peer-review of their drafts using a peer evaluation software. Peer review shifts the focus of instruction to the student creating a learner-centric approach to this aspect of project design. Collaborative learning through peer review promotes development of professional skills, as the ability to both give and receive constructive feedback are valuable skills in the workplace (Coleman, 1999). Peer-review also provides an opportunity for students to think critically about information and the method of presentation chosen by their classmates, providing a form of self-assessment (Pelaez, 2001). By evaluating each other’s papers, students are exposed to new methods of explanation or instruction and tend to improve their performance when both giving and receiving peer-feedback. After peer-review, students revised and reformatted their draft to create a second draft in Google Sites including text, multimedia, illustrations, etc. according to their own design and at their discretion. A tutorial for using Google Sites was provided. Second drafts also underwent peer review after which students generated their final drafts taking peer evaluations into account. To ensure that the resource remains up-to-date and useful, in future semesters students will have the option of analyzing and revising already published material to reflect current data or improve its presentation.

Data collection and analysis

For the first iteration (pilot study) reflections were collected from students (n=4) and data was compiled in the form of researcher memos. Students filled out 4 reflections periodically throughout the design process. During the first iteration, students reflected on areas of difficulty, the value of the assignment to their learning experience, and suggested improvements in instructional design for future semesters. Participating in reflection allows students the opportunity to revisit what they believe they have learned to personalize their knowledge, create connections, and identify potential deficiencies in understanding or instructional design (Chang, 2019). Participating in reflection increases the students' awareness that they are constantly learning and improving their skills, demonstrating that there is value to be gained even in learning from oneself (Heyer, 2015). By involving students in the scholarship of teaching and learning through the development and pilot of this assignment, the focus shifts to active participation in a learner-centric constructivist approach which promotes engagement and agency among students further cementing learned material. Based upon student feedback and instructor observations, we crafted design moves which were implemented in the second iteration in the whole class (n=164).

During the second iteration of the project, every 4 weeks students were asked to reflect on their progress and suggest improvements to the instructions or activity design. Student reflections and suggestions will be taken into account to revise future iterations of this design-based project.

Reflections were coded in MAXQDA Analytics Pro according to the Chi (1997) methodology for analyzing qualitative data to determine emerging themes. An open coding methodology was used to categorize student reflection responses. Open coding generated 357 codes and 6025 coded segments. Reflection responses were then recoded axially into predetermined categories related to design principles to evaluate learning theory (Corbin and Strauss, 2014). Axial coding of responses generated 955 coded segments and 58 codes. Response frequencies were evaluated.

Pearson's correlations of coded responses were calculated within MAXQDA Analytics Pro software and exported as excel files containing correlation matrices where significance was considered at $P \leq 0.05$. Matrices were imported into UCINET social network analysis software (Borgatti et al., 2002), and analyzed using NetDraw software (Borgatti, 2002). Connectedness and hierarchical clusters of responses were analyzed using the Girvan-Newman algorithm to identify response clusters (Girvan and Newman, 2002). Clusters were then used to evaluate and generate design moves.

Findings

Iteration 1

Issues identified by feedback of students in iteration 1 along with instructor memos were assembled and analyzed to develop design moves for implementation in iteration 2 (Table IV.1).

Table IV.1. Instructor observations and student feedback regarding project design issues and proposed design moves to improve project design in future iterations.

Iteration 1 Issues	Design Move
Peer-review responses vague or unhelpful	• Provide resource for formulating effective constructive critiques. • Use software that allows for evaluation of quality of peer review.
Difficulty keeping track of due dates	• Implement modular design in LMS where a submission is due every 2 weeks
Need more frequent feedback	• Implement 2 peer review and 2 additional progress checkpoints by the instructor
Difficulty connecting information with class notes	• More frequent discussions of project in class
Need support in finding information databases	• Provide links to library database and links to databases like ScienceDirect and PubMed
Unequal distribution of work and effort within group	• Provide regular opportunities for evaluation of group members' performance and contribution for the project.

Student feedback in the first iteration centered around peer and instructor feedback, organization of assignments, and difficulties locating useful information. To address these issues, we implemented a modular activity design in the second iteration where the project was split into 6 blocks, each containing an overview of the instructions, helpful readings and resources, and an assignment submission page to break the project into more manageable segments, gradually increasing in complexity (Figure IV.2). After every second block, students also provided reflections and suggested

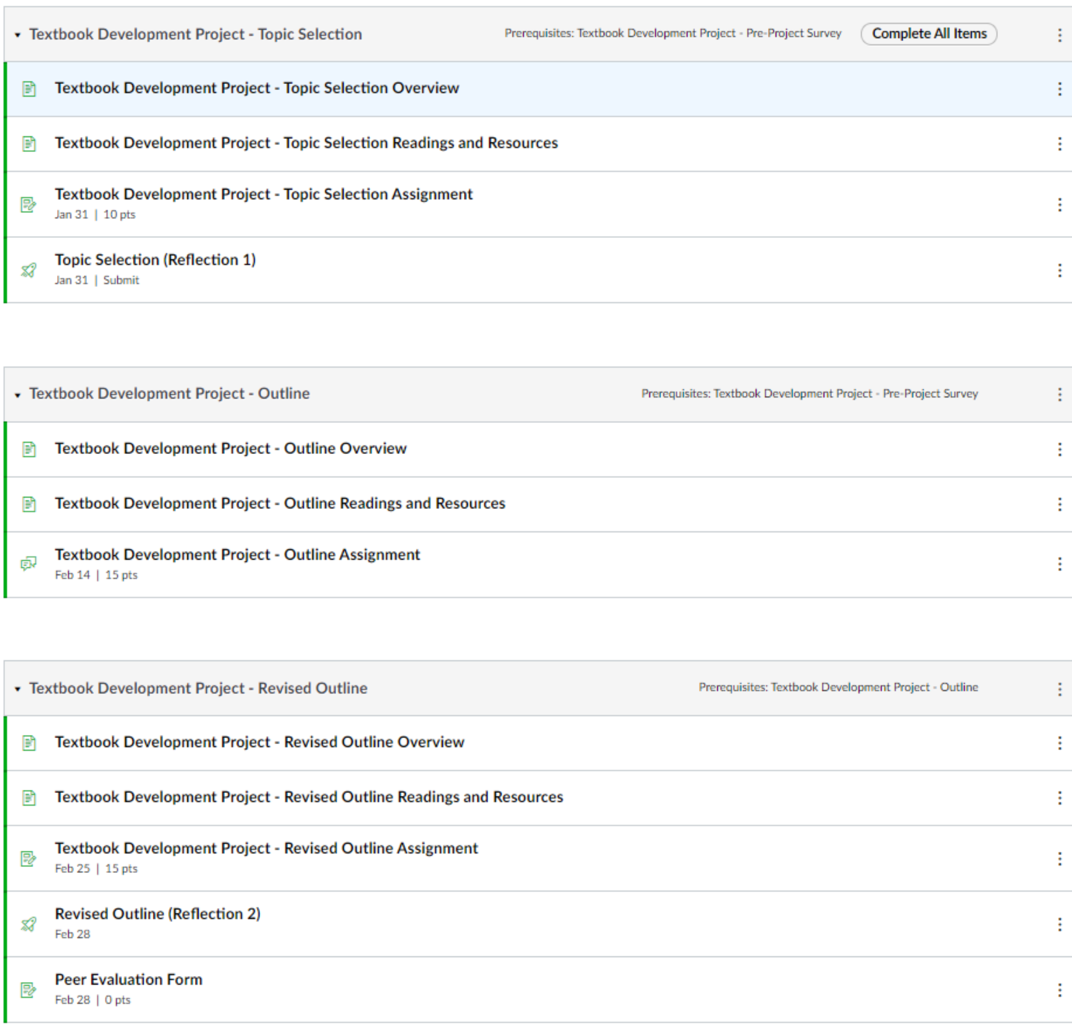


Figure IV.2 Excerpt from modular instructional design in Learning Management System for Development of the Living Digital Reference, iteration 2.

improvements in project design or instructions for future semesters. Iteration 2 included readings and resources within each block designed to address issues reported by students in the first iteration. Some of these resources included instructions for effective peer review and examples of both effective and ineffective reviews to improve constructive critiques provided by students. Additionally, a peer evaluation software was used to provide quality control of peer reviews. Links to library databases and links to other useful databases and sites like Web of Science or the CDC website were included within the modules as well in response to student feedback.

In the first iteration of the project only one peer review was performed, and students had one opportunity for instructor feedback prior to final product submission. Students desired more feedback, so during the second iteration an additional peer review was added as well as 2 opportunities for formal feedback from the instructor prior to submission of the final product. Finally, unequal distribution of work within groups was identified by the instructor as a potential issue so a group evaluation form was developed where group members were able to evaluate member contributions to the group project. These evaluations were submitted every 4 weeks, and grades for the assignment associated with the submission were adjusted accordingly.

Students also identified issues through their reflections during the second iteration of this project. Student feedback and instructor observations were used to develop design moves for the next iteration of this project (**Error! Reference source not found.**.) Design moves were generated by calculating Pearson's correlations of reflection responses combined with social network analysis.

Use of social network analysis and Girvan-Newman hierarchical evaluation provided insight into reflection responses. Use of network analysis, particularly cluster analysis in semantic networks as a tool in axially coding of qualitative data in learning design, is a novel methodology we are currently developing. Using the Girvan-Newman algorithm (Girvan and Newman, 2002) responses were clustered based upon connectedness of the concepts. Emerging clusters visually illustrate closeness of the coded responses through application of the algorithm. If clustering was effective, we took the next step of interpreting the clusters to translate to design moves. Because items within clusters are semantically related, we can identify strengths within a cluster to address weaknesses within the same cluster or closely associated clusters. For example, students who "Disagree" or "Strongly Disagree" with the statement "I can create

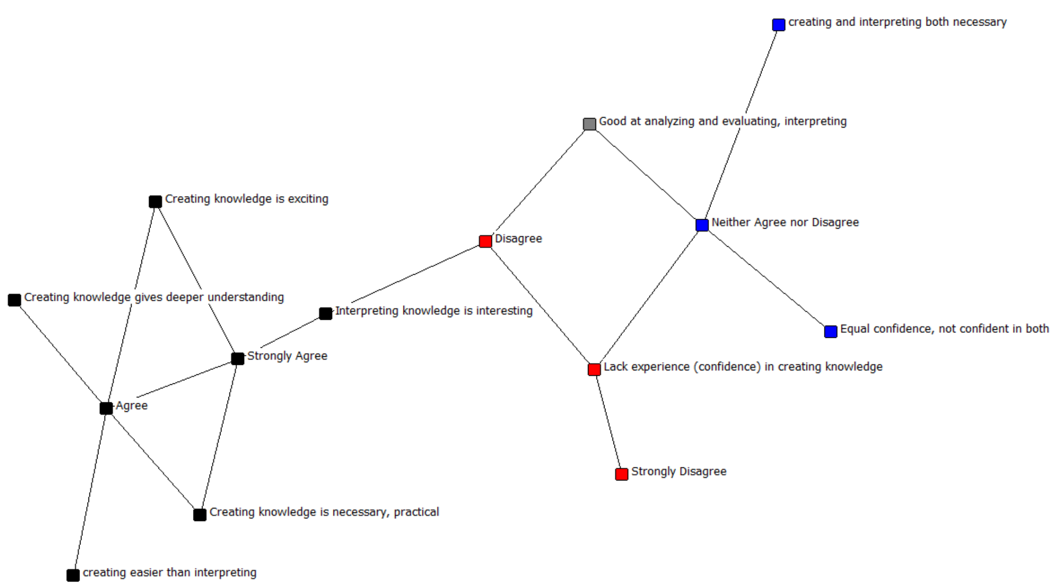


Figure IV.3. Social network analysis and Girvan-Newman clusters of knowledge creation prompt. Q = 0.381

knowledge" indicated that they did so because they lack experience and confidence in creation of knowledge. Consequently, the resulting design move is to provide detailed instructions and examples of knowledge creation and instances where students are already participating in the creation of knowledge (Figure IV.3).

Iteration 2

Student feedback during iteration 2 (Table IV.2) stemmed primarily from a lack of understanding of some aspect of the project. Much of students' uncertainty focused on misunderstanding instructions or lack of clarity in the expectations for the final product. Lack of understanding also extended to confusion over the topic, research methods, or formatting of citations. Many students (47.8%) desired greater specificity in instructions regarding expectations for the final product and examples for guidance. During the next iteration of this project, students will be directed to the webpages created during iteration 2 as examples of the possibilities for project development. Our observations indicated that students tended to skip over helpful resources and instructions and progress directly to assignment submission. Thus, they would miss important content resulting in grade penalties. In future iterations we will use the progressive feature of the LMS to require students to open each page of the module in order before they can access the assignment. Students also exhibited difficulty selecting appropriate search terms, and quickly became frustrated if their initial search proved fruitless. A video workshop about selecting and narrowing down search terms will be provided with modular readings and resources for future iterations. Additional guidance will also be provided to assist students in using information databases and generating citations.

Table IV.2. Issues identified by student feedback and instructor observations* in iteration 2 and proposed design moves to improve project design in future iterations.

Iteration 2 issues	Design Move
Lack confidence in creating knowledge	• Provide instructions/explanations to help students understand that creating knowledge is something they can already do because learning is knowledge construction. • Provide examples of knowledge construction to boost confidence and agency. • Examples provided will illustrate value of knowledge construction.
Lack of understanding of topic, expectations, citations* research methods, and feedback.	• Use LMS feature to require progression through each page of module before students can access the assignment to ensure each student accesses available resources and instructions*. • Provide examples (point to previous semesters' work). • Instructions will articulate expectations clearly, and rubrics will be accessible before assignment is due. • Provide feedback primarily through rubrics, less free-form feedback*. • Provide brief overview of each topic when making topic selections. • Provide additional resources, instructions, and examples for citations. • Provide workshop about selecting search terms*. • Create tutorial for using technologies.
Difficulties when navigating outside of the LMS	• Use peer review instrument within LMS to reduce confusion. • All due dates will be provided in syllabus and course calendar at the beginning of the semester through the LMS. • Create additional page in LMS with due dates and overview of instructions of each deliverable*. • Provide students with directions to access LMS tutorials*.
Group conflicts, communication, scheduling	• Create group contracts where students agree upon roles, expectations, and accountability with oversight from the instructor.

* Issue or design move generated from instructor observation rather than student feedback.

Students were also confused when asked to navigate outside of the Learning Management System (LMS) to complete assignments and struggled to keep up with due dates of assignments outside of the LMS. In fact, 48.7% of respondents indicated that this aspect of the project was problematic. In future iterations, the outside peer evaluation software will not be used, and all aspects of the assignment will be completed within the LMS. An additional page will be provided within the LMS containing due dates and instructions for each submission at the beginning of the semester. Lastly, a tutorial will be created by the instructor to facilitate easy navigation through the LMS and modular project system.

Although students identified collaboration with their group as a positive component of the project, (19.2%) and many had no issues within their groups (33.1%), 26.5% of students identified scheduling meetings, group conflict or lack of communication as a challenge to their success in this project. For the next iteration, a group contract will be developed by students to provide accountability and mitigate social loafing. Using these contracts, students will agree on regular meeting times, expected contributions by members, and penalties for failing to meet contractual requirements.

As this project continues to develop in future semesters, continuous evolution of instructions and resources provided will provide valuable insight and direction for students to improve their learning experience.

Discussion:

In addition to allowing continuous design evolution of a learning intervention, design-based research speaks back to the theory on which it was predicated. Findings support or problematize some aspect of the theory on which the innovation was grounded and can be used to refine learning theory to improve its applicability in a practical setting. Our study was grounded in *constructivist* and *constructionist* theories which gave rise to 5 design principles. Those based on *constructivist* theory, 1) learners use information as raw materials for the construction of knowledge 2) knowledge is co-constructed through social negotiation. And those derived from *constructionist* theory 3) facilitating development of learner agency, 4) learners transform information into knowledge and knowledge artifacts with a real-world audience, and 5) making involves tinkering and exploration.

Design principle 1. Learners use information as raw materials for the construction of knowledge.

Constructivism is a combination of both cognitive and social construction of knowledge (Piaget and Cook, 1952; Vygotsky, 1980). According to cognitive constructivism, students gather, organize and integrate information to construct knowledge (Piaget, 1977). In practice, students used both their personal experiences, existing knowledge, and new information gained through research to construct new knowledge. Students relied on their own experiences, familiarity, and knowledge to determine credibility of sources and importance of information for inclusion in construction of knowledge for their project. Additionally, students evaluated sources by comparing them to each other, examining references, and researching contributors to determine validity of information. However, students struggled to gather and evaluate information when the process was not adequately scaffolded. For example, students struggled to use information databases, or to understand available information about their topic as the process of gathering and organizing information was not well explained or demonstrated. Therefore, students were forced to rely more heavily on their previous knowledge or experiences, which at times was inadequate to promote deeper understanding and accurate construction of knowledge.

Design Principle 2. Knowledge is co-constructed through social negotiation.

Vygotsky (1980) asserts that knowledge is constructed through a process of social negotiation where knowledge construction depends upon the social context of the learner and collaboration with others within their community. Therefore, other learners can affect construction of knowledge either positively or negatively. In the context of developing our digital reference, learners benefitted from both peer and instructor feedback. Collaboration with others helped students to develop and refine interpersonal and communication skills and to cement learning through the process of peer instruction. However, without adequate scaffolding of collaborative work, collaboration can be a detriment to the learner. For example, uneven distribution of work and communication issues were cited as problematic within several groups. Students also tend to approach group projects as cooperative rather than collaborative learning. When working cooperatively, students work on some aspect of the project on their own then bring their work back to the group. Collaborative learning is accomplished through collective construction of knowledge, where work is completed within the group rather than individual setting (McInnerney and Roberts, 2009). A collaborative approach is more closely aligned with social constructivist theory and generally leads to more powerful learning (Panitz, 1999). Additionally, peer reviews were at times unhelpful or inconsistent which created confusion for the learners. Diligent scaffolding of the process of peer review and collaboration including defining roles within a group and providing accountability will mitigate some of these issues.

Design Principle 3. Facilitating development of learner agency

Development of learner agency occurs through allowing autonomy and authority over development of knowledge and knowledge artifacts. Development of knowledge artifacts reflects the knowledge of the learner, creating a sense of ownership over both the artifact and the knowledge itself (Papert and Harel, 1991). Agency within the context of this project led to excitement over creating knowledge, and confidence in overcoming obstacles. Additionally, students reported greater self-reliance, leadership, and a desire to learn promoted by the authority allowed them over their choice of topic and its presentation. Again, however, information and processes must be scaffolded as impediments to learner agency include a lack of confidence or experience in creating knowledge, and confusion over unclear instructions or expectations of the final product. Guidance for knowledge construction is required but should not diminish the authority of the student in construction of the knowledge artifact.

Design Principle 4. Learners transform information into knowledge and knowledge artifacts with a real-world audience.

Construction of knowledge artifacts operates in a feedback loop according to constructionist learning theory, whereby the artifact is developed concurrently to construction of meaning. Construction of that artifact informs construction of knowledge, which contributes to artifact development in a continuous cycle (Papert, 1993). In practice, transformation of knowledge into a knowledge artifact depends upon the knowledge and experiences of the learner and the ability of the learner to scaffold information to construct new knowledge. Scaffolding of the knowledge artifact was promoted in this context by breaking the project into smaller pieces for submission, thereby making knowledge construction gradual and more manageable for the student. Development of the artifact also informed knowledge construction of the learner as students developed new methods of presenting information, communicating scientific concepts to lay audiences, or examined their own perceptions of potential career or research interests. Construction of the knowledge artifact contributed to deeper understanding of the course material and personal connections with the knowledge being developed.

Design Principle 5. Making involves tinkering and exploration.

Construction of knowledge and knowledge artifacts requires development of skills and expression of creativity. As students created their digital reference pages, they developed their research skills, learned how to use new technologies, and cultivated their interpersonal skills by working within their groups. Students were also encouraged to think creatively to present their topic and creatively format their sites to promote visual appeal and interactivity. However, difficulties with new technologies can be a barrier to exploration. Without a proper introduction to and instructions for new technologies, rather than serving as a useful tool to promote skill creativity and skill development, they become a source of frustration and an obstacle to knowledge construction.

A prominent finding related to many of our design principles is that if adequate scaffolding of tasks and knowledge is lacking, student success becomes more difficult. Many of the issues that arose over the course of this project would have been mitigated by effectively scaffolding knowledge and processes. Without scaffolding, learners are likely to remain in the zone of achieved development, relying on their individual knowledge (Vygotsky, 1978), and will not advance through the zone of proximal development to learn and master new skills and integrate new knowledge.

Zone of proximal development

The zone of proximal development is a concept introduced by Vygotsky (1978) which describes the potential of an individual for achievement and learning either aided or unaided. Vygotsky's theoretical framework expands from the learner's demonstrated individual capabilities to potential competence that may be developed through collaboration or guidance from experts or more knowledgeable peers, and finally, to achievements that are outside of the current capabilities of the learner. The zone of proximal development is defined as the level of competence that cannot be achieved through individual efforts but can be reached through collaboration or guidance from more expert individuals. These ideas formed the basis of Vygotsky's social constructivist theory, where learning is achieved through co-construction of knowledge and collaboration with more knowledgeable others. Although the concept of scaffolding was not initially included in the explanation of the zone of proximal development, it has since been identified as a method to encourage mastery with the zone of proximal development (Stone, 1998). Scaffolding as a learning concept was developed more explicitly by Bruner (1974) where initially, greater levels of support are provided to the learner and over time the support structure decreases until the learner is independently responsible for that stage of their learning. As the learner continues to progress, new scaffolds are constructed and dismantled (Harland, 2003). Effective scaffolding is crucial to the learning process and provides students with enough support to encourage their progress without providing a crutch for their development (Reiser and Tabak, 2014). Provision of too much information or support will not encourage students to make connections on their own, discouraging problem-solving and knowledge retention. Conversely, too little support or information can cause students to become overwhelmed as the cognitive load is too great (Wittwer and Renkl, 2010). Effective scaffolding promotes deeper understanding, accurate construction and retention of knowledge, and development of important skills that endure even when support is unavailable. In this manner, scaffolding knowledge and processes can move the zone of proximal development so that responsibility is transferred to the student, and students are more expert when faced with similar tasks in the future (McNeill et al., 2006; Shabani et al., 2010). Scaffolding can be incorporated into knowledge construction through activities like active questioning, or it can used to increase proficiency with processes or technical skills. For example, if students are using a new technology, a tutorial can provide initial guidance through available features; or if students have never before participated in the process of peer review, scaffolding of the process may include specific prompts and questions to ponder when conducting their review.

Scaffolding is a component of social constructivism, but is not present in cognitive constructivism (Vygotsky, 1978). Papert and Harel (1991) described constructionism as a further development of cognitive constructivism where internal construction of knowledge leads to construction of knowledge artifacts. We believe that constructionist theory would be more powerful with the integration of social constructivist principles. The idea of scaffolding speaks back to our design principles and the learning theories on which this project was based. Although some scaffolding was provided in artifact development by breaking the project into incremental submissions, scaffolding of collaborative work, peer review, and expectations for the final product were inadequate. Without provision of effective scaffolding of tasks and knowledge, students became frustrated, unable to discern the expectations of the instructor and were confused about which direction to take their projects. Lack of scaffolding also impacted student agency. Students lacked confidence in their ability to create knowledge and present knowledge to their peers. Scaffolding in the form of leading questions, examples, or topical breakdowns would mitigate this issue. Frustrations generated through lack of scaffolding decreased motivation and confidence in students' ability to effectively complete the knowledge artifact.

Conclusions

The living, student-created digital reference generated as a product of this assignment will have great utility in the field of food-bacteriology, creating an ever-evolving course resource for students and other learners. Conducting this project using a design-based approach not only allows continuous improvement of the learning activity, but it also helps to elucidate issues in constructionist learning theory. It is clear from our findings, that constructionist theory is strengthened through the incorporation of ideas and design principles originating in constructivist learning theory, incorporating effective scaffolding of both knowledge and processes to promote deeper understanding, motivation, and agency among students.

References

Anderson, L. W., and B. S. Bloom. 2001. A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Longman.

Barron, B. 2000. Achieving coordination in collaborative problem-solving groups. The journal of the learning sciences 9(4):403-436.

Blikstein, P. 2008. Travels in Troy with Freire: Technology as an agent of emancipation, Social Justice Education for Teachers. Brill Sense. p. 205-235.

Borgatti, S. 2002. NetDraw software for network visualization. Analytic Technologies., Lexington, USA.

Borgatti, S. P., M. G. Everett, and L. C. Freeman. 2002. Ucinet for Windows: Software for Social Network Analysis. Analytic Technologies, Harvard, MA

Bruner, J. S. 1974. From communication to language—A psychological perspective. Cognition 3(3):255-287.

Chang, B. 2019. Reflection in learning. Online Learning 23(1):95-110.

Chi, M. T. 1997. Quantifying qualitative analyses of verbal data: A practical guide. The journal of the learning sciences 6(3):271-315.

Coleman, J. 1999. Groupware: Collaboration and knowledge sharing. In: J. Liebowitz, editor, Knowledge management handbook. CRC press, Boca Raton. p. 12.11-12.15.

Corbin, J., and A. Strauss. 2014. Basics of qualitative research: Techniques and procedures for developing grounded theory. Sage publications.

Design-Based Research Collective. 2003. Design-based research: An emerging paradigm for educational inquiry. Educational researcher 32(1):5-8.

Donaldson, J. P. 2019. Conceptualizations of learning in the learning sciences and STEM education. Drexel University.

Galarza, S., S. Perry, and S. Peyton. 2017. A student-created, open access, living textbook. Chemical Engineering Education 51(1):2-9.

Gerlach, J. M. 1994. Is This Collaboration? New directions for teaching and learning 59:5-14.

Girvan, M., and M. E. Newman. 2002. Community structure in social and biological networks. Proceedings of the national academy of sciences 99(12):7821-7826.

Harland, T. 2003. Vygotsky's zone of proximal development and problem-based learning: Linking a theoretical concept with practice through action research. Teaching in higher education 8(2):263-272.

Heyer, R. 2015. Learning through reflection: The critical role of reflection in work-based learning. Journal of Work-Applied Management 7(1):15-27.

Hoadley, C. M. 2004. Methodological alignment in design-based research. Educational psychologist 39(4):203-212.

Jiake, L., Z. Wei, and W. Xuan. 2010. Design and evaluation of a wiki-based collaborative learning environment for colleges computers compulsory education. In: 2010 5th International Conference on Computer Science & Education. p 695-699.

Johnson, D. W., and R. T. Johnson. 1994. Learning Together. In: S. Sharan, editor, Handbook of cooperative learning methods No. 51. Greenwood Press/Greenwood Publishing Group. p. 65.

Kafai, Y. 2005. Constructionism. In: R. Sawyer, editor, The Cambridge Handbook of the Learning Sciences (Cambridge Handbooks in Psychology, pp. 35-46). Cambridge University Press, Cambridge.

McInnerney, J. M., and T. S. Roberts. 2009. Collaborative and cooperative Learning, Encyclopedia of Distance Learning, Second Edition. IGI Global. p. 319-326.

McNeill, K. L., D. J. Lizotte, J. Krajcik, and R. W. Marx. 2006. Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. The Journal of the Learning Sciences 15(2):153-191.

Panitz, T. 1999. The Case for Student Centered Instruction via Collaborative Learning Paradigms.

Papert, S. 1993. The children's machine: Rethinking school in the age of the computer. ERIC.

Papert, S., and I. Harel. 1991. Situating constructionism. Constructionism 36(2):1-11.

Pelaez, N. J. 2001. Calibrated peer review in general education undergraduate human physiology. In: Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science, Costa Mesa, CA. p 1518-1530.

Piaget, J. 1977. The development of thought: Equilibration of cognitive structures.(Trans A. Rosin). Viking.

Piaget, J., and M. T. Cook. 1952. The origins of intelligence in children.

Reiser, B. J., and I. Tabak. 2014. Scaffolding, The Cambridge Handbook of the Learning Sciences, Second Edition. Cambridge University Press. p. 44-62.

Sandoval, W. A., and P. Bell. 2004. Design-based research methods for studying learning in context: Introduction. Educational psychologist 39(4):199-201.

Shabani, K., M. Khatib, and S. Ebadi. 2010. Vygotsky's zone of proximal development: Instructional implications and teachers' professional development. English language teaching 3(4):237-248.

Sinatra, G. M., B. C. Heddy, and D. Lombardi. 2015. The Challenges of Defining and Measuring Student Engagement in Science. Educational Psychologist 50(1):1-13. doi: 10.1080/00461520.2014.1002924

Skinner, E., E. Saxton, C. Currie, and G. Shusterman. 2017. A motivational account of the undergraduate experience in science: brief measures of students' self-system appraisals, engagement in coursework, and identity as a scientist. International Journal of Science Education 39(17):2433-2459.

Stager, G. 2005. Papertian constructionism and the design of productive contexts for learning. In: Proceedings of EuroLogo. p 43-53.

Stone, C. A. 1998. The metaphor of scaffolding: Its utility for the field of learning disabilities. Journal of learning disabilities 31(4):344-364.

Vygotsky, L. 1978. Mind in Society. Cambridge MA. Harvard. University Press. Wenger, E.(1998) Communities of Practice: Learning ….

Vygotsky, L. S. 1980. Mind in society: The development of higher psychological processes. Harvard university press.

Wittwer, J., and A. Renkl. 2010. How effective are instructional explanations in example-based learning? A meta-analytic review. Educational Psychology Review 22(4):393-409.

CHAPTER V

FOSTERING SCIENCE IDENTITY, MOTIVATION, AND ENGAGEMENT THROUGH A STUDENT-CREATED LIVING DIGITAL REFERENCE IN FOOD MICROBIOLOGY

Synopsis

A strong STEM identity increases engagement, motivation, persistence and success within STEM disciplines and career paths. Currently, many instructional practices in STEM promote acquisitional conceptualizations of learning where students rely on extrinsic motivators. Such a conceptualization may stunt intrinsic motivation and lead to greater attrition in STEM disciplines. We seek to address this issue through innovative learning design based the constructionist and constructivist theories of teaching and learning. Over the course of a semester, students collaboratively constructed a section of a food bacteriology textbook in their own vernacular. This reference will be used as an evolving course resource for future classes. Using the dynamic systems model of role identity, we studied the effect of collaborative construction of a knowledge artifact with real-world application on development of science identity. Findings from this study indicate that developing this constructionist digital reference enhance self-efficacy and perceived agency, and development of identity through collaborative learning. Emotional engagement was promoted through this project design which influenced motivation, and goals of the students. Self-perceptions and perceived action possibilities were also influenced by this project. Learning principles applied in the design and implementation of this project extend beyond the field of food microbiology and may be applied to other STEM disciplines where the goal is to improve science identity among students.

Introduction

Often within STEM courses, instructors hold a conceptualization of learning that relies on transfer and acquisition of knowledge, termed instructionism. This conceptualization of learning gives rise to related practices in teaching and assessment like the traditional lecture delivery format, drill and practice, and multiple choice exams to evaluate comprehension (Papert and Harel, 1991; Donaldson, 2020). Although widely used, such practices promote an acquisitional conceptualization of learning where students rely on extrinsic motivators and see themselves as consumers of information rather than active participants in the construction of knowledge. Such a conceptualization of learning is inversely related to intrinsic motivation and engagement, and may stunt development of a science-identity which is vital to success and persistence within STEM majors and career paths (Hanrahan, 2002; Handelsman et al., 2005; Olson and Riordan, 2012; Skinner et al., 2017). Conversely, we propose an innovative learning intervention based upon an alternative conceptualization of learning as the construction of meaning and "becoming" in the context of a role or community. This collaborative project is grounded in self-determination theory (Deci et al., 1991; Ryan and Deci, 2000; Deci and Ryan, 2012; Ryan and Deci, 2017) which states that students have an intrinsic need for self-efficacy, agency, and belonging, which if met, increases motivation and engagement, and promotes development of a science identity.

A strong science identity assigns value and emotional significance to scientific pursuits fostering a greater degree of investment in their work and increasing the learner's motivation to engage with and strive to overcome cognitive challenges (Chang et al., 2011; McDonald et al., 2019). Perceived value is especially linked to the learner's belief that they can master a task or topic. Lack of self-efficacy can undermine motivation and engagement within the STEM classroom (Brookhart, 1997; Velayutham et al., 2011). Conditions or learning interventions which promote competency, agency, and belonging within a scientific community are crucial to promote and maintain intrinsic motivation in STEM students. In turn, intrinsic motivation is vital in creating self-determined behavior. By increasing self-efficacy, students' interest in learning, value assigned to STEM education, and confidence in their own abilities likewise increases. Outcomes from increased self-efficacy and self-determination are improvements in conceptual understanding, personal growth, and ownership of learning (Deci et al., 1991; Ryan and Deci, 2000; Deci et al., 2001).

One of the highest forms of engagement is not intellectual engagement, but engagement of the whole person, which has identity at its core. If learning is defined as becoming, then learning necessarily involves identity work which requires identity development to facilitate change. Identity and its development are nebulous concepts that are difficult to define conclusively although it can be agreed that a learner's identity has strong correlation with self-perceptions, intrinsic motivation, and potential actions taken in pursuit of their purpose or goals (Glynn and Koballa, 2006; Oyserman et al., 2006; Chang et al., 2011; Adedokun et al., 2013; Kaplan and Garner, 2017). Identity development is a multi-faceted process shaped by psychological, cultural, and social influences in a complex and dynamic system. As such, discussions of identity development are incomplete if focused on a single aspect and must include multiple perspectives which lead to self-identification as the kind of person who can succeed in a specific role which in turn generate related behaviors (Schwartz et al., 2011; Kaplan and Garner, 2017).

Within STEM disciplines there is value to investigating pedagogical approaches which emphasize development of a science identity and increase motivation and engagement within the science classroom. Such an approach requires adopting a generative conceptualization of learning, and strategies which promote self-efficacy, autonomy, and belonging within a community of practice to promote science identity. Engagement, identity, belonging within a community, and self-perceptions of ability collectively influence motivation and learning outcomes (Velayutham et al., 2011). Active engagement in constructing knowledge through construction of knowledge artifacts is a valuable motivational resource and is highly correlated with science identity, a sense of purpose within STEM, and pursuit of science career paths (Papert, 1993; Skinner et al., 2017). Our goal is to produce a pedagogical framework for student creation of a living digital reference and to assess its effect on development of science identity among STEM students. Design of this learning activity is based upon constructionist and constructivist theories of teaching and learning where learning is defined as construction of knowledge through construction of knowledge artifacts (Piaget and Cook, 1952; Vygotsky, 1980; Papert and Harel, 1991; Papert, 1993). Student created textbooks have been studied in small-enrollment courses (Donaldson and Bucy, 2016; Galarza et al., 2017b), but have not been implemented to our knowledge in large-enrollment science courses.

Therefore, we seek to determine if a constructionist approach to learning in STEM through construction of a student-created living digital reference that will be used as a course resource is effective in promoting science identity among undergraduate students in a food microbiology course. Our goal is to optimize learning through promoting development of science identity and collaboration in an upper-level science course. In this research study we analyzed student reflections and surveys regarding their experiences over the course of a project in which they developed and contributed to an online digital reference that will be used as a course resource in future semesters. Our analysis attempts to reveal insights into the utility of similar learning interventions in other science courses to promote deeper learning and science identity.

Methods

We carried out this study using a convergent parallel mixed methods design where both qualitative and quantitative data were collected, analyzed independently, and interpreted concurrently (Creswell and Pablo-Clark, 2011). This type of experimental design and analysis satisfies the parameters described by Yin (2018) where multiple sources of data and analytical processes are necessary for robust design case studies. Such an approach allows for corroboration between quantitative and qualitative results through comparison.

Context

A learning activity was created where students (n = 184) in a food microbiology course worked collaboratively to generate a student-created living reference that will be used as a continuously evolving course resource for future semesters. Our eventual goal for this assignment is that the student-created reference will take the place of the course textbook and be available as an open access resource to others within the food microbiology discipline. Students worked in groups of 3 to conduct research on a subtopic within the field of food microbiology identified by the professor as having great significance to the course. In the first step of this project students indicated their interest in food microbiology subtopics by ranking them on an interactive sign-up sheet (Google

Sheets). Students were grouped according to similar interests, and we strove to ensure that students were assigned one of their top three topics. Students worked collaboratively within their groups to complete the project, progressing in stages where submissions became gradually more complex from an outline to project drafts and finally to the final submission. This project was presented in a modular format through the learning

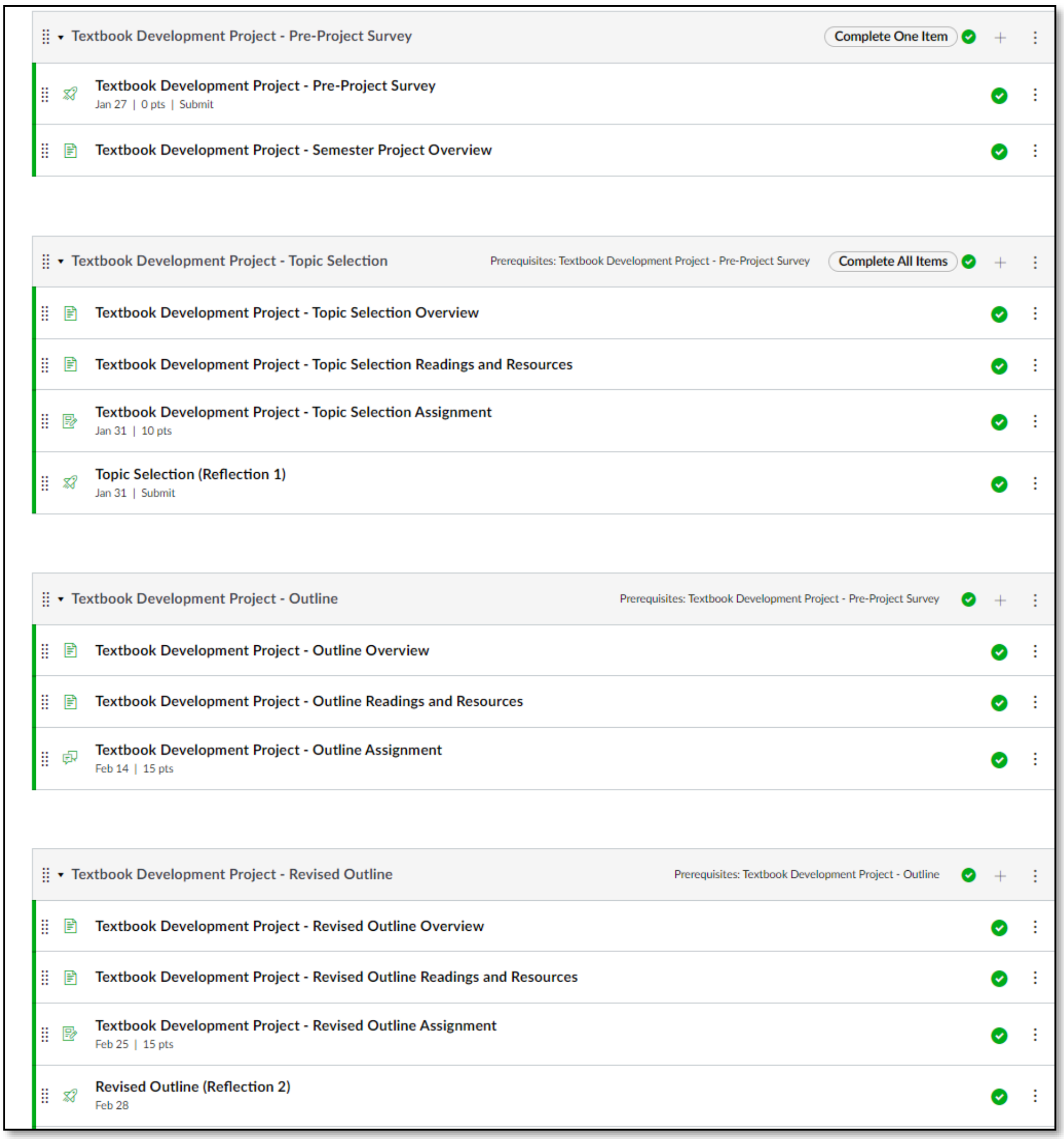


Figure V.1. Modular presentation of the project in the Learning Management System.

management system where each module contained an overview of the assignment, instructions for submission, and additional resources to support student success (Figure V.1).

Students submitted a portion of the assignment every 2 weeks with each module equating to one submission. Modules included in this assignment were Topic Selection, Outline, Revised Outline, First Draft for peer review, Second Draft for peer review, and the Final Submission. Resources about assessing source credibility, reading scientific articles, conducting constructive peer-review, citing sources, and avoiding plagiarism were provided. Students were given creative license to present their topic in whatever manner was chosen by their group. Topical material was collected and assembled in formats chosen by the students including multimedia, text, diagrams, or videos. We chose to use the Google Sites platform to create our digital reference as it is supported by the University, does not require knowledge of coding or advanced technical skills to use, and allows inclusion of various types of multimedia. Students were encouraged to present information in their own vernacular in whatever manner they deemed most beneficial to communicate complex concepts and information to their peers. Subtopics completed by the students were then combined into a living, student-created digital reference organized in sections similar to a traditional textbook. This resource will continue to evolve semester by semester as new discoveries are made, technologies are developed, and as future students make new connections. Students in future semesters will either revise existing topics to reflect new information or discoveries or will contribute novel topics to the reference. This student-created living reference will be available as a course supplement for future students in food microbiology and is intended to eventually take the place of the course textbook.

Data Collection and Analysis

Periodically throughout the project, students were given opportunities to reflect on their progress and identify strengths and weaknesses of the project design according to their experiences. Student responses will be taken into account in subsequent iterations of this project to improve its implementation in the future. Allowing students this type of input not only improves project design but increases student agency as they impact the flow of instruction. Additionally, prior to beginning their project and immediately after completing the artifact, students completed a Likert scale survey to assess the impact of the project on measures of motivation, identity, and belonging. Originally, we had planned to use a validated Likert scale survey developed by Skinner et al. (2017) to assess the impact of construction of a course resource on engagement, science identity, and motivation. However, this survey contained too much extraneous information pertaining to the class at large rather than the project in specific. This made separating the impact of the project from the class at large difficult and did not prove useful for analysis. However, some questions from the survey were retained as they applied directly to the project at hand. We also added several of our own questions to the survey to assess the effect of the project on the following measures of interest: confidence in science communication, expertise in the subject of food microbiology, motivation to continue investigation of class subjects outside of course assignments, confidence in evaluating source credibility.

Total Likert scale scores within each theme were calculated by averaging the Likert scale responses. Negatively valanced items were reverse coded before being averaged. Statistical analysis of pre- and post-test responses were performed using a two-tailed t-test with heteroskedastic variance to assess changes in responses before and after participating in this learning activity.

Kaplan and Garner (2017) proposed a dynamic systems model of role identity (DSMRI) which provides a framework for identity development that takes into account the complex systems dynamics where alterations to one element create a ripple effect through the entire system. Using this framework, we developed several systems measures to assess the value of this innovative learning activity in influencing development of scientific identity. We used these measures to create 4 coding categories that are related to identity development. Themes identified to create categories are Self-Efficacy and Perceived Agency, Collaboration and Belonging (Teamwork, Peer Learning and Instruction), Motivation and Goals, and Science and Professional Identity. Student reflections were coded in MAXQDA Analytics Pro using an open coding methodology first according to the prompt to which students were responding (Chi, 1997). Open coding of 357 text documents generated 236 codes, with 6039 coded segments. Reflection responses were then recoded axially to fit the prescribed themes we identified according to the DSMRI framework (Corbin and Strauss, 2014). Axial coding generated 28 codes and 469 coded segments.

All procedures and data collection were approved by the Texas A&M University Institutional Review Board, IRB2020-0983M, and students provided informed consent for the use of their data.

Findings

Students successfully completed their subtopic pages for inclusion in the digital reference. Groups were creative in their approaches, using diagrams, creating infographics, text, and videos to explain their topic to their peers. One group even chose to create a video series describing methods of reducing *Listeria monocytogenes* through thermal processing of different foodstuffs (Figure V.2), while others created games or activities to test background knowledge and comprehension of their audience. Some groups selected a more traditional approach using text and images to disseminate information which was also a valid approach (Figure V.3).

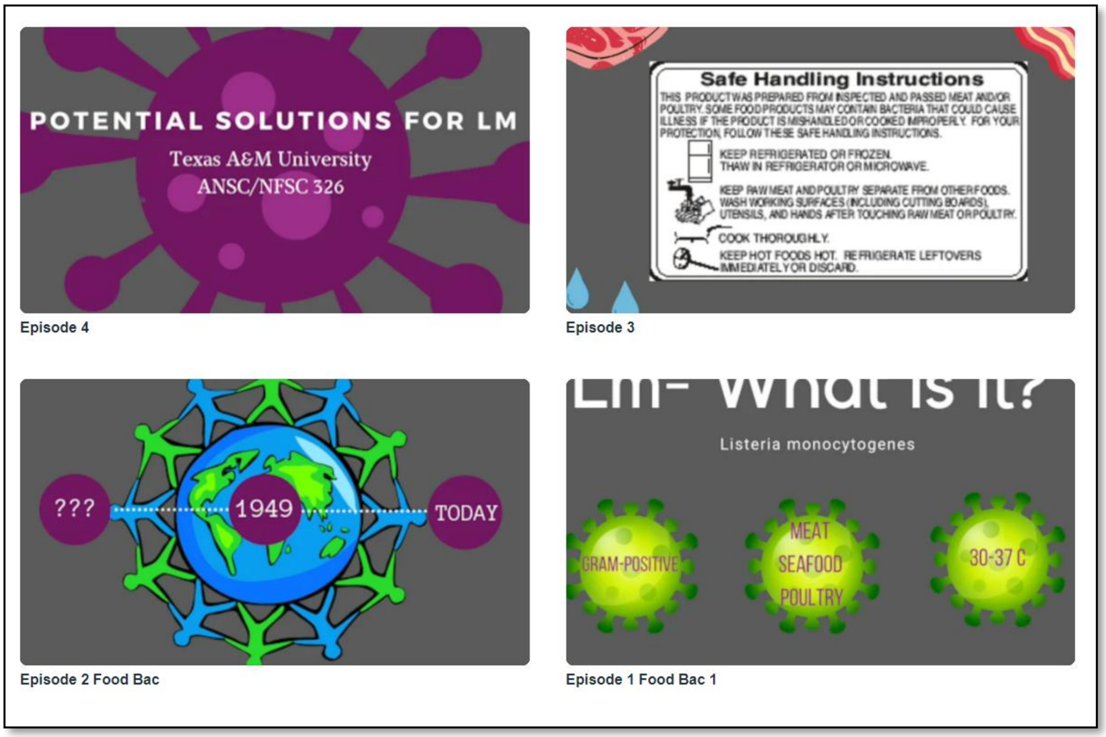


Figure V.2. Still shot of the student-created video series on Listeria monocytogenes reduction through thermal processing and safety protocols. This excerpt is from the Gram-positive bacterial pathogens section of the digital reference, under the sub-heading "Listeria monocytogenes".

Introduction

Clostridium botulinum (*C. botulinum*) is a spore-forming, anaerobic bacterium which produces a botulinum toxin that causes a neuroparalytic disease most commonly known as botulism. Although it is rare, botulism is severe and causes nerve function to be blocked resulting in flaccid paralysis, respiratory failure, and even death (Harvard Health Publishing, 2019). As a spore-former, botulinum spores survive in non-acidic conditions and tend to be most prevalent in improperly canned low-acid canned foods and honey. Improperly preserved vegetables such as asparagus, green beans, and corn are at high risk of harboring *C. botulinum*. Other low acid foods such as fish and seafood can also harbor this bacteria and its spores. (FSIS, 2013)

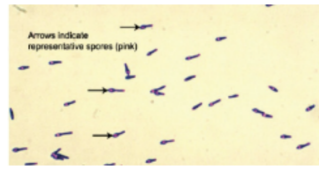


Figure 1: *Clostridium botulinum exemplifying spore formation*, (Caitlin et al., 2003)

Characteristics of Botulism

Who is most susceptible to botulism infection/intoxication?

Botulism can be acquired through the ingestion of *C. botulinum* spores or botulinum toxins and the disease commonly categorized into four primary classes: adult, infant, wound, and indeterminate. The primary categories which apply to food bacteriology are adult and infant. Although botulism is caused by the same bacteria in both infants and adults, the common modes of disease transmission vary significantly between the two. As a foodborne disease, botulism can be caused by either an infection or intoxication. A botulism **infection** is disease caused by ingestion of viable *C. botulinum* spores resulting in colonization of the intestinal tract and is most commonly observed in *infant botulism*. A botulism **intoxication** is disease resulting from direct ingestion of the toxin produced by *C. botulinum*, and is most frequently observed in *adult botulism* (Jackson et al., 2017).

	Died	*Survived*	*Percent mortality*	*OR (95% CI)*
Age (years)				
<1	17	2,327	0.7	Referent
1–9	3	40	7.0	10.3 (2.9–36.4)
10–19	2	56	3.4	4.9 (1.1–21.7)
20–29	6	154	3.6	5.3 (2.1–13.7)
30–39	8	245	3.2	4.5 (1.91–10.5)
40–49	11	262	4.0	5.8(2.7–12.4)
50–59	23	200	10.3	15.4 (7.2–33.0)
60–69	12	107	10.1	15.4 (7.2–33.0)
70–79	15	58	20.6	35.4 (16.9–74.3)
≥80	11	21	34.4	71.7 (30.0–171.4)
Unknown	1	39	2.5	4.4 (0.6–34.2)

Figure 2: *Mortality Rate of Botulism in the U.S. from 1975 to 2009. (Jackson et al., 2017)*

Infant Botulism

According to an article published by NCBI in 2017, 65.0% of confirmed reports of botulism incidents from 1975 to 2009 were infant botulism (Jackson et al., 2017). Infants are most susceptible to botulism infection through ingestion of spores via food or placing contaminated objects such as soil into their mouths (Barous et al., 2018). Once *C. botulinum* enters the gastrointestinal tract of an infant, it reproduces and colonizes within the intestines. The absence of infant gut flora enables *C. botulinum* to reproduce without competition (Jordan et al., 2018). The most common vehicle of transmission in infants is through **honey** which can contain low amounts of *C. botulinum* spores capable of causing disease in individuals with immature immune systems.

Figure V.3. Excerpt from student-created reference page on "Characteristics of Botulism, and Foods that Serve as Pathogen Vehicles." This page is from the Gram-positive Bacterial Pathogens section of the digital reference under the sub-heading "Toxigenic Clostridium Species in Human Food."

Students appreciated the opportunity to demonstrate their creativity and present information in a novel way, as many had never submitted a research project in a format other than a formal paper.

> *I also love that Google sites is used to format the final project because it is a useful and engaging way to present complex and challenging information.*

I think the Google Sites was the best aspect of this project. It was easy to collaborate and organize with my group members. It also allowed the format to not be strictly essay format the way a Word Doc might have.

Google Docs and Google Sites provided effective collaborative platforms for students to work together remotely and should be utilized for other types of collaborative work.

In this study we sought to reveal insights into affective factors that influence identity development prompted by constructionist learning in a STEM classroom. We divided our findings into themes according to the DSMRI (Kaplan and Garner, 2017) framework to describe the effects of this project on Identity Development. This framework describes development of identity as a complex dynamic system in which components are interrelated and in a constant state of emergence as changes in each component echo through the entire system to generate actions. Major findings related to themes within this system include increased feelings of self-efficacy, connectedness, changes in purpose and goals, self-perceptions and perceived action possibilities. Findings related to Likert scale questions are summarized in **Table V.** and these domains are further explored in the following sections.

Table V.1. Likert scale survey of STEM engagement, motivation and science identity pre- and post-test themes and responses

Theme	**Pre-test mean*[A]**	**Post-test mean**	***P* - value**
Positive Relationships and Collaborations	2.73	2.89	0.05
Purpose in Science	4.34	4.30	0.32
Science Career Plans	4.04	4.06	0.77
I feel confident communicating scientific ideas to my peers	3.16	3.48	<0.001
I am motivated to seek out additional information independent of class work in a subject I am interested in.	3.67	3.65	0.88

Table V.1. Likert scale survey of STEM engagement, motivation and science identity pre- and post-test themes and responses, continued

Theme	Pre-test mean*[A]	Post-test mean	***P*** **- value**
I am confident in evaluating sources of information for credibility and usefulness.	3.88	4.04	0.08
I feel that I can provide considerable expertise in the subject of food microbiology.	2.88	3.43	<0.001

*Likert scores were evaluated from 1 to 5 with 1 being “Strongly Disagree” and 5 being “Strongly Agree”.
[A] Negatively valanced questions were reverse coded prior to evaluating the mean.

Self-Efficacy and Perceived Agency

According to self-determination theory (Deci and Ryan, 2012; Ryan and Deci, 2017), learners across backgrounds and circumstances possess intrinsic psychological needs that if met will increase engagement and motivation to learn. Two of these fundamental needs are competence and autonomy (Ryan and Deci, 2017). That is, students must believe that they are capable and experience feelings of ownership and authority which in turn translate into engagement and motivation to succeed (Skinner et al., 2017). Agency is highly correlated with motivation, as students take ownership of their own work and learning. Agentic engagement, whereby students feel a deep personal commitment to project development and learning, goes hand in hand with competence, that is, greater agency contributes to greater perceptions of self-efficacy (Deci et al., 2001; Reeve, 2002; Sinatra et al., 2015). Perception of self-efficacy is strongly related to motivation and engagement in STEM and contributes to persistence within STEM majors and career paths (Adedokun et al., 2013). If students do not feel competent, or feel that their authority is undermined, they can become discouraged, resentful, and disillusioned with the process (Skinner et al., 2009). Feelings of self-efficacy and competence provide motivation to engage with cognitive challenges which leads to deeper learning. Learning requires cognitive engagement, as internal struggles with current conceptualizations allows conceptual changes to occur (Sinatra et al., 2015).

Pedagogical strategies and interventions based in constructivist and constructionist learning theories leverage these ideas to generate deeper learning as students demonstrate the construction of knowledge through construction of knowledge artifacts (Papert, 1993; Ackermann, 2001). Self-determination theory intersects with the constructionist design of this project as both self-efficacy and autonomy are promoted through the development of knowledge artifacts with real-world utility (Brown and King, 2000; Stager, 2005; Adedokun et al., 2013; Skinner et al., 2017). Students were aware that their contributions to the digital reference will be used by future food microbiology students which lends greater personal value to its development (Brown and King, 2000). Additionally, although subtopics were selected by the instructor, students were given authority over their choice of subtopic and the development of their contribution to the digital reference which lends greater personal significance to the project and increases students' motivation and interest in their topic (Papert, 1993; Donaldson and Bucy, 2016), demonstrated by participant reflections.

> *I think being able to have a choice in what topic we wanted made the project more interesting.*

As students developed their subtopic, their confidence in their own abilities increased, which will positively affect their future performance (Bandura and Locke, 2003). Students reported that participating in this project increased confidence in their abilities to communicate scientific ideas to their peers (3.16 to 3.48; $P < 0.001$). Students also tended to feel more confident in their ability to evaluate sources of information for credibility and usefulness after completing this project (3.88 to 4.04; $P = 0.08$) This quantitative finding is further demonstrated by participant reflections about their experiences.

> *Finding resources became easier over time. It has given me peace of mind to find articles in the future when I am curious about a topic.*

Initially students were not confident in their ability to construct or create knowledge, feeling more comfortable in evaluating existing knowledge.

> *I understand how to take material that is given to me, learn it, and be able to apply knowledge gained from that material to be successful on exams and projects. I have always struggled, however, in creating something new.*

However, through cognitive struggles and successes, students prove their competence to themselves which contributes to development of identity through perceptions of self (Velayutham et al., 2011; Sinatra et al., 2015; Skinner et al., 2017) as illustrated in participant reflections.

> *I feel I can break things down and explain and create new ways for people to understand topics on a deeper level and really understand all the way through.*

Collaboration and Belonging

Social context of learning is an important component of identity development according to the DSMRI framework (Kaplan and Garner, 2017). Additionally, the third component of self-determination theory which contributes to motivation and engagement in STEM is relatedness, or feelings of belonging within a community of practice (Deci and Ryan, 2012; Ryan and Deci, 2017). This finding is echoed in situated learning theory where learning is defined as “becoming” in the context of a community of practice. Learners engage with the community to gain diverse perspectives, knowledge, and experiences which contribute to understanding. Collaboration within the community facilitates the co-construction of knowledge which in turn contributes to feelings of connection and belonging. In this sense, learners identify as part of a scientific community of practice as they engage with others to contribute ideas and develop expertise (Lave and Wenger, 1991; Stein, 1998). Supportive relationships with others within a community of practice is linked with persistence and success in STEM courses and career paths (Skinner et al., 2017).

Collaborative learning was a major aspect of this project where group members worked together to develop their knowledge artifact. Collaborative learning activities encourage positive interaction between peers in the course and help students to develop a support system within their discipline. This increases feelings of belonging within the classroom community which in turn creates a more positive learning environment (Panitz, 1996). Our findings indicate that positive relationships and collaborations between classmates increased as a result of this project. (2.73 to 2.89; P = 0.05). Students reported that,

> *Working with a group made it easier to take on the whole project and it didn’t seem as overwhelming because we worked on it together.*

However, not all students had the same positive experience, although 47.2% of students reported positive experiences with collaboration, about 21.3% expressed frustration with social loafing or uneven distribution of work among their group members and 7.9% cited issues with their group dynamic with one student saying, *We are having trouble with working together at the same time and ensuring that everyone is on the same page without stepping on people's toes.*

These issues could be mitigated by following the suggestion of Donaldson and Bucy (2016) to create a group contract which outlines member expectations, responsibilities, and accountability. Additionally, these issues could be mitigated through reworking the instructions of the assignment to facilitate true collaborative rather than cooperative work (Dillenbourg, 1999).

Despite issues, students recognized that learning to work collaboratively is an important practical skill which helps to increase competence and confidence when entering the workforce (Kuh et al., 2006). Indeed, professional development through collaborative work in the academic setting is identified by employers as vital for prospective employees when entering the workplace. Many employers expect students to already have developed some collaborative skills prior to entering the workforce (Coleman, 1999; Barron, 2000; Colbeck et al., 2000; Donaldson and Allen-Handy, 2020). Students echoed these sentiments, viewing collaborative work as essential for their personal and professional development and contributing to their feelings of competence as discussed in the previous section.

In the professional world, communication skills, effective collaboration with peers, and technological knowledge are some of the most valuable skill sets for an individual to possess in a career.

I will most likely have to work in teams when I graduate and learning how to communicate with others to get a job done is essential. This project required a lot of coordination and working together so it was good practice for the future.

I want to be an online Nutritionist Coach and considering that involves working with patients over the internet and in person, this project is as if I am working with other people. It relates in a way that allows me to learn how to communicate with other people, and working together to achieve a certain goal, or task.

Activities in STEM courses which promote relatedness and belonging through collaboration also contribute to identity development as students feel a greater sense of connection with the scientific community. Connection to the scientific community is associated with increased engagement, motivation, and persistence within STEM. Relatedness and belonging are especially important components to development of a strong science identity and success in STEM in historically underrepresented populations (Fisher et al., 2019).

Additionally, situated learning theory includes identity development through peer learning and instruction (Stein, 1998). Students engage and interact with each other, learning from the experiences and expertise of their classmates. Peer review is one mechanism by which peer learning and instruction can be facilitated. Galarza et al. (2017b) suggested the addition of a peer review component in their discussion of the development of a digital textbook in a tissue engineering course. Abiding by this suggestion, we included two opportunities for peer review to facilitate peer learning and instruction over the course of this project. Peer review provides an opportunity for critical assessment and metacognitive evaluation of others' work which in turn prompts self-reflection (Pelaez, 2001). Learning occurs through the exchange of knowledge and expertise among peers at a comparable zone of proximal development, as students are able to offer each other understanding, scaffolding, and useful suggestions that the instructor may not, the instructor has not been in that particular zone of proximal development in quite some time (Vygotsky, 1980; Harland, 2003).

> *I always appreciate when a fellow student offers suggestions as to where I can improve in my clarity and presentation. Reading another person's perspective on the topic that I am writing about is constructive and truly enlightening.*

Students appreciated the perspectives of their peers and the learning experience of evaluating others which exposed them to new information and unique perspectives and methods of presentation that they may use in the future to improve their own project design.

> *I liked being able to look at other students' projects to understand how they were formatting their papers and website pages. This allowed us to not only learn new information while peer-reviewing but make our page cohesive with the rest of the website to appeal to readers.*

Although learners benefitted from both giving and receiving peer review, saying,

> *I enjoy the collaborative nature of peer review because it is always a valuable, constructive learning experience that benefits both the student and peer reviewer.*

Others lacked confidence in their ability to provide effective evaluations saying,

> *I found it challenging to make sure I was giving good feedback. It's hard to know what a good paper is when I am trying to create one just the same.*

This issue could be addressed through proper scaffolding of the process of peer review, providing guiding questions and examples of constructive feedback to improve the experiences of both the reviewer and the reviewee.

Through collaboration within their groups and through the process of peer-review, students move from a novice to a more expert designation within their community of practice in accordance with situated learning theory (Lave and Wenger, 1991; Stein, 1998). In this way, development of a strong science identity is encouraged through community development and belonging through this collaborative learning activity.

Purpose and Goals

Purpose and Goals are another component of identity development outlined in the DSMRI framework (Kaplan and Garner, 2017). Personal connections and relevance contribute to an individual's purpose and goals. Students with a strong sense of scientific purpose feel confident that their work in the science classroom and knowledge they are building can be used to contribute to society. These students assign value to what they are learning that goes beyond the classroom which affects their future goals and plans and strengthens their motivation to succeed in the face of adversity. Without a sense of purpose, students in STEM often feel adrift and can become overwhelmed by the academic rigor required in upper-level science courses. These feelings can lead to emotional and behavioral disaffection, as learners cultivate a belief that it is not worth the effort needed to succeed in science (Skinner et al., 2017).

Alternatively, a strong sense of scientific purpose is linked to emotional engagement with the subject which in turn is linked with intrinsic motivation (Sinatra et al., 2015). Emotion is an integral component of identity development where learners are searching for personal relevance in what they are learning which can then be incorporated into their identity as a learner. This type of engagement is particularly important in students who are trying to define their place in a new environment (Christie et al., 2008). Emotional engagement occurs when students discover personal connections with course material, recognizing its relevance to their current lives or goals for the future (Sinatra et al., 2015). Students who are emotionally engaged in scientific pursuits are more likely to develop a strong sense of scientific purpose which contributes to stronger science identity. In this course, a majority (54.3%) have career goals that contribute to a strong sense of scientific purpose. These students intend to pursue careers directly related to science like nutrition, human or veterinary medicine, or dietetics. Additionally, another 25.5% of students intend to pursue science adjacent careers like food safety or animal agriculture, while about 20.2% of students intend to pursue non-science careers like business or law (Figure V.4).

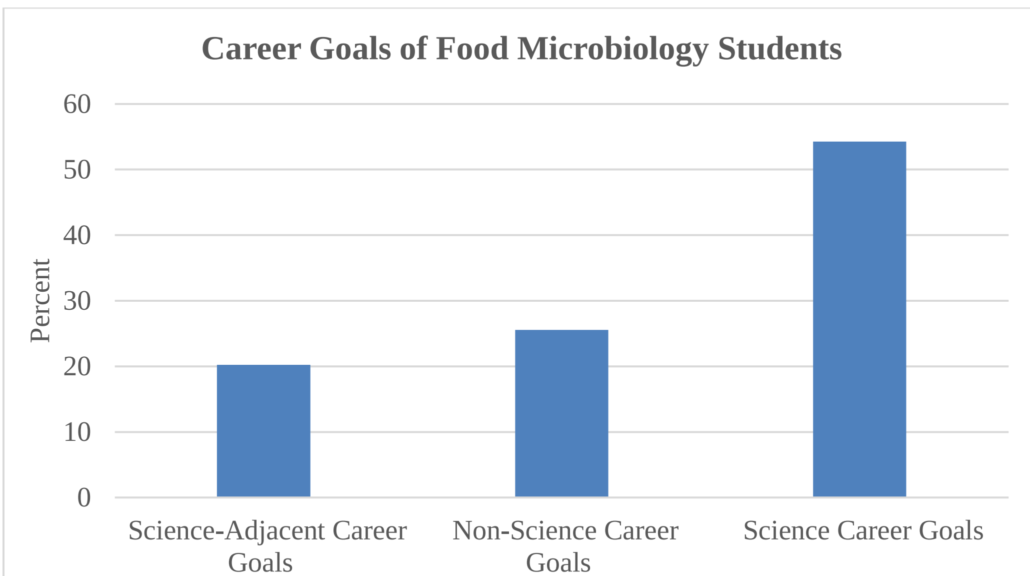


Figure V.4. Career goals of students in the food microbiology course, Spring 2021.

According to the pre- and post-project surveys, students in this upper-level food microbiology course already had a strong sense of purpose in science that was not affected by participation in this project (4.34 to 4.30; $P = 0.32$). Additionally, the proportion of students who indicated that they have science career plans did not change as a result of this project (4.04 to 4.06; $P = 0.77$). However, although students did not indicate changes in their intent to pursue careers in science, through constructing this digital reference, several students discovered personal and global relevance to the information they were researching. Emotional engagement with the course material led to curiosity and investigation into new career avenues or interests which was expressed in their reflections about the project.

> *I was definitely more intrigued by the career of food microbiology. It led me to researching fields and jobs that I might consider.*
>
> *I am interested in going into sales, but this project made me realize that there are other things I am interested in and working with others in order to share valuable information with consumers was something I enjoyed doing.*

For some students, this project has direct relevance to their future plans which increases engagement and motivation. For others, although the project itself did not apply to their career aspirations, skills acquired through development of their subtopic for the digital reference relates to their career goals.

> *In the future, as a dietitian, I probably might need to conduct research about a topic and this project involved some of that aspect. I also plan to start my own business and learning to use google sites might be something useful.*

Even for those students who do not have aspirations in STEM, participation in a constructionist project like this helps them to develop personal competence and professional skills which are applicable to many types of future careers (Kuh, 2008a). These students were able to engage emotionally and find personal relevance and value in the process of developing this resource rather than the knowledge itself.

I really don't think any of the technical work relates to my future endeavors, but the researching will directly help me in my future career in law school and as an attorney.

Although students in this class reported no changes in their motivation to seek out additional information independent of classwork in a subject of interest as a result of participating in this project (3.67 to 3.65; $P = 0.88$), co-constructing this digital reference sparked new interest in the subject matter as they established personal connections which is demonstrated in their reflections,

I never had an interest in foodborne pathogens until entering this course and now I find myself thinking about this information as I cook, order food, or observe others handling food. I really like learning about different pathogens and what makes them dangerous in their own ways as well as how we attempt to battle this issue. Personally, I found the material which I was researching to be very insightful and interesting. There were global issues and practices I was unaware of before writing this paper.

Construction of this knowledge artifact facilitated emotional engagement among students which influenced their thinking about their purpose and career plans. As students recognize the value of science education to their future goals, a stronger science identity is promoted (Sinatra et al., 2015; Skinner et al., 2017).

Self-Perceptions and Perceived Action Possibilities

The manner in which a learner perceives and defines themselves within the context of their role as a STEM learner or scientist and possible actions that may be taken to achieve their goals in light of their self-perceptions are important to the development of science identity (Garner and Kaplan, 2019). This component of the DSMRI framework is strongly related to self-efficacy and agency discussed above (Kaplan and Garner, 2017; Ryan and Deci, 2017). Students who view themselves as the type of person who can succeed in science develop this self-perception largely in relation to competence and agency. Self-perceptions of the learner then influence perceived action potentials that may be undertaken to achieve a goal. When potential actions are aligned with goals or self-definitions, motivation to execute those actions increases (Garner and Kaplan, 2019). Therefore, developing skills and expertise within the context of food microbiology increases the likelihood that students will identify as the type of person who can succeed in science, increasing motivation to engage with scientific ideas and activities and leading to persistence within STEM disciplines and career paths (Skinner et al., 2017).

After completing their portion of the digital reference, students in this class reported increased feelings of expertise in the subject of food microbiology (2.88 to 3.43; $P < 0.001$). By co-creating their portion of the digital reference which will be used by future classes as a course reference, students' self-perceptions of themselves as experts or educators was promoted. Students indicated that they felt more equipped to educate others,

> *I think this project better prepared me to help educate patients on possible food storage tips, or even friends and family.*

They also frequently made connections between construction of this digital reference project and their plans for the future.

> *I think this project has helped me to become better at research and finding evidence for a topic unknown to me first. This will help in my future plans as a dietician in that I will be able to prove my findings to patients with research and articles.*

As students developed their research skills during this project, their perceived action possibilities expanded to include conducting research in their personal and professional lives and presenting complex scientific information to laypeople as they serve as an expert in the field.

> *In addition to deepening my scientific skills such as research and critical review of scientific literature, this project has helped me improve and refine my oral and written communication skills, interpersonal skills, and technology skills.*
>
> *I am working to become a Registered Dietitian and medical doctor. Both of these fields involve conducting primary research or reading about research in order to present it to an audience who may know little to nothing about a given topic. In the same way, this project relates to reading research papers and presenting it in a way that is easy to understand for an individual who is learning about the subject.*

Students' confidence in their abilities leads to perceived action possibilities that students otherwise would not have considered. For example, as students were situated as designers and developers of the digital reference, their confidence in presenting information in a similar manner in the future increased which creates an action possibility that was not previously feasible based on the learner's self-perception.

> *Learning how to use and make a website using google sites was, and is, going to be extremely useful. I feel way more comfortable being asked to make or create a website and feel confident I would succeed in the task.*

Students' self-perceptions of their capabilities were impacted through construction of this constructionist digital reference as they developed their research, collaboration, and communication skills.

Discussion

Innovative learning design grounded in STEM that is grounded in constructionist and constructivist learning theories provide fertile ground for future learning activities where the goal is to both increase content knowledge and develop the science identity of the learner. A strong science identity protects students from disaffection and apathy in science courses, promoting persistence and resilience among STEM students (Chang et al., 2011). Our findings suggest that a constructionist approach, whereby students are situated as designers of a knowledge artifact with real-world utility, is an effective approach in encouraging development of a strong science identity. Constructionist design promotes learner agency which encourages self-efficacy as students prove their competence to themselves (Papert and Harel, 1991; Skinner et al., 2017). Additionally, aspects of social constructivism (Vygotsky, 1978) and situated learning theory (Lave and Wenger, 1991) are incorporated into this project as meaning is collaboratively constructed, leading to identity development within the classroom community. Students were engaged behaviorally through participation in this project, emotionally as they were encouraged to discover personal connections and value. Agentic engagement was also promoted as learners took ownership of their product and satisfaction in the knowledge that an artifact of their creation will be used to help future students. Educators can leverage the power of DSMRI framework to design similar learning innovations that promote development of a science identity.

References

Ackermann, E. 2001. Piaget's constructivism, Papert's constructionism: What's the difference. Future of learning group publication 5(3):438.

Adedokun, O. A., A. B. Bessenbacher, L. C. Parker, L. L. Kirkham, and W. D. Burgess. 2013. Research skills and STEM undergraduate research students' aspirations for research careers: Mediating effects of research self-efficacy. Journal of Research in Science teaching 50(8):940-951.

Barron, B. 2000. Achieving coordination in collaborative problem-solving groups. The journal of the learning sciences 9(4):403-436.

Brookhart, S. M. 1997. A theoretical framework for the role of classroom assessment in motivating student effort and achievement. Applied measurement in education 10(2):161-180.

Brown, S. W., and F. B. King. 2000. Constructivist pedagogy and how we learn: Educational psychology meets international studies. International Studies Perspectives 1(3):245-254.

Chang, M. J., M. K. Eagan, M. H. Lin, and S. Hurtado. 2011. Considering the impact of racial stigmas and science identity: Persistence among biomedical and behavioral science aspirants. The Journal of higher education 82(5):564-596.

Chi, M. T. 1997. Quantifying qualitative analyses of verbal data: A practical guide. The journal of the learning sciences 6(3):271-315.

Christie, H., L. Tett, V. E. Cree, J. Hounsell, and V. McCune. 2008. 'A real rollercoaster of confidence and emotions': Learning to be a university student. Studies in higher education 33(5):567-581.

Colbeck, C. L., S. E. Campbell, and S. A. Bjorklund. 2000. Grouping in the dark: What college students learn from group projects. The Journal of Higher Education 71(1):60-83.

Coleman, J. 1999. Groupware: Collaboration and knowledge sharing. In: J. Liebowitz, editor, Knowledge management handbook. CRC press, Boca Raton. p. 12.11-12.15.

Corbin, J., and A. Strauss. 2014. Basics of qualitative research: Techniques and procedures for developing grounded theory. Sage publications.

Creswell, J. W., and Pablo-Clark, V. L. 2011. Designing and conducting mixed methods research. Sage. Thousand Oaks, CA.

Deci, E. L., R. Koestner, and R. M. Ryan. 2001. Extrinsic rewards and intrinsic motivation in education: Reconsidered once again. Review of educational research 71(1):1-27.

Deci, E. L., and R. M. Ryan. 2012. Self-determination theory.

Deci, E. L., R. J. Vallerand, L. G. Pelletier, and R. M. Ryan. 1991. Motivation and education: The self-determination perspective. Educational psychologist 26(3-4):325-346.

Donaldson, J. P. 2020. Conceptualizations of Learning in the Learning Sciences American Educational Research Association Annual Meeting, San Francisco, California.

Donaldson, J. P., and A. Allen-Handy. 2020. The nature and power of conceptualizations of learning. Educational Psychology Review 32(2):545-570.

Donaldson, J. P., and M. Bucy. 2016. Motivation and engagement in authorship learning. College Teaching 64(3):130-138.

Fisher, A. J., R. Mendoza-Denton, C. Patt, I. Young, A. Eppig, R. L. Garrell, D. C. Rees, T. W. Nelson, and M. A. Richards. 2019. Structure and belonging: Pathways to success for underrepresented minority and women PhD students in STEM fields. PloS one 14(1):e0209279.

Galarza, S., S. R. Peyton, and S. L. Perry. 2017. A Student-Created, Open Access, Living Textbook. In: 2017 AIChE Annual Meeting

Garner, J. K., and A. Kaplan. 2019. A complex dynamic systems perspective on teacher learning and identity formation: an instrumental case. Teachers and Teaching 25(1):7-33.

Glynn, S. M., and T. R. Koballa. 2006. Motivation to learn in college science. Handbook of college science teaching 25:V32.

Handelsman, M. M., W. L. Briggs, N. Sullivan, and A. Towler. 2005. A measure of college student course engagement. The Journal of Educational Research 98(3):184-192.

Hanrahan, M. U. 2002. Learning science: Revisiting humanist dimensions of intellectual engagement. Australasian Science Education Research Association

Harland, T. 2003. Vygotsky's zone of proximal development and problem-based learning: Linking a theoretical concept with practice through action research. Teaching in higher education 8(2):263-272.

Kaplan, A., and J. K. Garner. 2017. A complex dynamic systems perspective on identity and its development: The dynamic systems model of role identity. Developmental psychology 53(11):2036.

Kuh, G. D. 2008. High-impact educational practices: What they are, who has access to them, and why they matter. Association of American Colleges and Universities 14(3):28-29.

Kuh, G. D., J. L. Kinzie, J. A. Buckley, B. K. Bridges, and J. C. Hayek. 2006. What matters to student success: A review of the literature. National Postsecondary Education Cooperative Washington, DC.

Lave, J., and E. Wenger. 1991. Situated learning: Legitimate peripheral participation. Cambridge university press.

McDonald, M. M., V. Zeigler-Hill, J. K. Vrabel, and M. Escobar. 2019. A Single-Item Measure for Assessing STEM Identity. Frontiers in Education 4doi: 10.3389/feduc.2019.00078

Olson, S., and D. G. Riordan. 2012. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. Executive Office of the President

Oyserman, D., D. Bybee, and K. Terry. 2006. Possible selves and academic outcomes: How and when possible selves impel action. Journal of personality and social psychology 91(1):188.

Panitz, T. 1996. A definition of collaborative vs cooperative learning.

Papert, S. 1993. The children's machine: Rethinking school in the age of the computer. ERIC.

Papert, S., and I. Harel. 1991. Situating constructionism. Constructionism 36(2):1-11.

Pelaez, N. J. 2001. Calibrated peer review in general education undergraduate human physiology. In: Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science, Costa Mesa, CA. p 1518-1530.

Piaget, J., and M. T. Cook. 1952. The origins of intelligence in children.

Reeve, J. 2002. Self-determination theory applied to educational settings. Handbook of self-determination research 2:183-204.

Ryan, R. M., and E. L. Deci. 2000. Intrinsic and extrinsic motivations: Classic definitions and new directions. Contemporary educational psychology 25(1):54-67.

Ryan, R. M., and E. L. Deci. 2017. Self-determination theory: Basic psychological needs in motivation, development, and wellness. Guilford Publications.

Schwartz, S. J., V. L. Vignoles, and K. Luyckx. 2011. Epilogue: What's next for identity theory and research. Handbook of identity theory and research:933-938.

Sinatra, G. M., B. C. Heddy, and D. Lombardi. 2015. The Challenges of Defining and Measuring Student Engagement in Science. Educational Psychologist 50(1):1-13. doi: 10.1080/00461520.2014.1002924

Skinner, E., E. Saxton, C. Currie, and G. Shusterman. 2017. A motivational account of the undergraduate experience in science: brief measures of students' self-system appraisals, engagement in coursework, and identity as a scientist. International Journal of Science Education 39(17):2433-2459.

Stager, G. 2005. Papertian constructionism and the design of productive contexts for learning. In: Proceedings of EuroLogo. p 43-53.

Stein, D. 1998. Situated learning in adult education. ERIC Clearinghouse on Adult, Career, and Vocational Education, Center on ….

Velayutham, S., J. Aldridge, and B. Fraser. 2011. Development and validation of an instrument to measure students' motivation and self-regulation in science learning. International Journal of Science Education 33(15):2159-2179.

Vygotsky, L. 1978. Mind in Society. Cambridge MA. Harvard. University Press. Wenger, E.(1998) Communities of Practice: Learning ….

Vygotsky, L. S. 1980. Mind in society: The development of higher psychological processes. Harvard university press.

Yin, R.K., 2018. Case study research and applications. Sage.

CHAPTER VI

CONCLUSIONS

Incorporation of high impact teaching and learning practices increase student engagement and motivation in STEM. Practices like experiential learning, incorporation of constructivist and constructionist ideals, and novel approaches to teaching notoriously difficult concepts will help students to develop personal connections with course material. Such innovations engage students not only behaviorally, but emotionally by forging personal connections and assigning value to course material and the ways it can become applicable to their personal lives. Even if students do not perceive a direct connection with the subject in question, development of new skills and ways of thinking are recognized as valuable to students as it pertains to their future careers and personal lives. Skill development and novel approaches to learning facilitate cognitive engagement encouraging students to wrestle with existing perceptions and incorporate new ideas into their knowledge framework. Lastly, high-impact teaching practices like those described in this dissertation engage students agentically, providing a sense of ownership and authority over their learning. By engaging students in the process of reflection and incorporating their ideas and feedback into future instructional design, students feel a sense of pride and greater connection to both the course and the academic community. By grounding interventions and design of learning activities in learning theory, instructors have a theoretical basis for their expectations of potential outcomes for students. Additionally, data generated by implementing educational interventions and innovations will be valuable in refining our understanding of theories of teaching and learning upon which these interventions are based. As these theories are explored and refined, our ability to generate future interventions and educational innovations will be enhanced, promoting greater learning outcomes for future generations of students.

APPENDIX A

DRAWING TO LEARN AS A PEDAGOGICAL STRATEGY IN NUTRITIONAL PHYSIOLOGY ANIMAL SCIENCE COURSE, ACTIVITY INSTRUCTIONS AND RUBRIC ITERATION 1

Instructions Activity A Iteration 1:

Using the blank diagrams attached to this assignment, create visual representations of the metabolism of non-structural and structural carbohydrates in the cow and either the pig or the horse.

You should provide 3 copies of the nonruminant diagram and 3 copies of the ruminant. Each diagram should have unique features that are different on each copy within a species.

Diagrams should illustrate structural and non-structural carbohydrate digestion and absorption beginning in the mouth through the reticulorumen or stomach, small intestine, and large intestine including waste.

Be sure to include secretion, activation, coenzymes, activity, reactions, and products of relevant enzymes. You should also include fermentation, microbial specific enzymes, activity and products where appropriate.

Your diagram should also include absorption of nutrients in the correct location whether that is the rumen, stomach, small intestine or large intestine.

Be sure also to include transport of nutrients to other organs and utilization of nutrients in the body if relevant.

You will also need to complete 1 copy of the nonruminant lipid enterocyte and 1 copy of the ruminant lipid enterocyte using the blank enterocyte diagrams provided. Include Na/K pump, transporters, and electrolyte concentration gradients in your enterocyte diagrams.

For this activity you will have 14 total drawings.

Sample Rubric Activity A, Iteration 1

Item	Score 5	Score 3	Score 2	Score 0
Enzymes	All relevant enzymes are included along with correct secretion, activation, coenzymes, activity and products	All relevant enzymes are included, < 4 errors in secretion, activation, coenzymes, activity or products	> 4 relevant enzymes missing, ≥ 5 incorrect or absent secretion, activation, coenzymes, activity or products	Enzymes are not included
Absorption	Absorption of correct nutrient products are displayed in appropriate locations with no errors	Absorption of nutrient products are displayed in appropriate locations with < 2 errors	Absorption of nutrient products are displayed in inappropriate locations or are not present, ≥ 3 errors	Absorption of nutrient products is absent
Enterocyte	Absorption into and out of enterocyte is illustrated including Na/K pump activity related or relevant transporters with no errors	Absorption into and out of enterocyte is illustrated including Na/K pump activity related or relevant transporters with < 3 errors	Absorption into and out of enterocyte is illustrated Na/K pump activity is not included, or ≥ 4 errors in related or relevant transporters	Absorption into and out of enterocyte is not illustrated
Utilization	Basic utilization of nutrients is shown, destination of nutrient products is present; no errors	Basic utilization of nutrients is shown, destination of nutrient products is present; < 3 errors	Basic utilization of nutrients is shown, destination of nutrient products is present; ≥ 4 errors	Utilization of nutrients is not present
Fermentation	Microbial fermentation is illustrated where appropriate including microbial enzymes and products; no errors	Microbial fermentation is illustrated where appropriate including microbial enzymes and products; < 4 errors	Microbial fermentation is not included in appropriate location; microbial enzymes and products are missing	Microbial fermentation is not included

Figure A.1 Rubric Activity A, Iteration 1

APPENDIX B

DRAWING TO LEARN AS A PEDAGOGICAL STRATEGY IN NUTRITIONAL PHYSIOLOGY ANIMAL SCIENCE COURSE, ACTIVITY

INSTRUCTIONS AND RUBRIC ITERATION 2

Activity A Instructions, Iteration 2

Due Date: 3/15/2021 11:59 PM – No Late Assignments will be accepted. Review Due Date: 3/17/20212 11:59 PM – No Late Reviews will be accepted.

- ✓ Maximum 5 paragraphs
- ✓ 12 point Times New Roman Font
- ✓ 1” margins
- ✓ Double Spaced
- ✓ Don’t write name on document
- ✓ Include the prompt selected as a title
- ✓ Work independently
- ✓

Prompts: 1) Comparing Cellulose Digestion, Absorption, and Metabolism in Horse and Cow; 2) Comparing Starch Digestion, Absorption, and Metabolism in Horse and Cow

Sample Rubric Activity A, Iteration 2

Grading Rubric – Note: When using this rubric for someone to receive the highest rating they must have achieved all of the attributes of the lower rating.

Item	**Exemplary (7)**	**(6)**	**Proficient (5)**	**(4)**	**Sufficient (3)**	**(2)**	**Developing (1)**
Attention to Directions (15%)	Included three animal drawings and enterocyte		Included prompt as title		Maximum 5 Paragraphs		Correct Font & Spacing, Name NOT Included
Grammar/Conventions (15%)	Writer does not make any errors in grammar or spelling that distracts the reader from the content. No sentences start with "**The**".		Writer makes less than three errors that distract the reader from the content.		Writer makes less than five errors that distract the reader from the content.		Writer makes more than five errors that distract the reader from the content.
Structure/Organization (15%)	The entire paper has a clear thesis and paragraphs have clear points that tie to one another.		Paragraphs have clear points and are easy to follow.		Sentences are well organized and easy to follow.		Details are not in a logical order. There is little sense the writing is organized.
Drawings (15%)	Drawings are easy to read and tidy.		Drawings include highlights to demonstrate and support the major points in the paper.		Drawings contain all of the required information.		A drawing of a horse, a pig, a cow, and an enterocyte is included.
Paper Content (40%)	More than three correct comparisons between species are made and accurately supported. At least two limitations/benefits are discussed.		Three correct comparisons between species are made and accurately supported. Additionally, one limitation/benefit is discussed.		Two correct comparisons between species are made and supported.		One correct comparison between species is made and supported.

Figure A.2. Sample Rubric Activity A, Iteration 2

APPENDIX C

DRAWING TO LEARN AS A PEDAGOGICAL STRATEGY IN NUTRITIONAL PHYSIOLOGY ANIMAL SCIENCE COURSE, POST-ACTIVITY SURVEY

Please answer the following questions honestly, your answers are anonymous and will not affect your grade. Your responses will be used to evaluate the effectiveness of this learning activity and to improve it for future semesters.

1. Complex nutritional concepts were easier to grasp and explain to others after I completed this paper.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree
2. I believe I will retain the information from this learning activity beyond the next exam.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree
3. Completing this activity helped me to integrate and apply concepts covered in class.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

4. This activity made it easier to compare concepts learned for one animal with another.

    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree

5. This activity was a helpful study aid for the exam.

    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree

6. I plan to use this method to study for other classes.

    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree