EXAMINING PORTFOLIO-BASED ASSESSMENT IN AN UPPER-LEVEL BIOLOGY COURSE

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Examining Portfolio-Based Assessment in an

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ABSTRACT

Historically, students have been viewed as empty vessels and passive participants in the learning process but students actually are active forming their own conceptions. One way student learning is impacted is through assessment. Alternative assessment, which contrasts traditional assessment methods, takes into account how students learn by promoting engagement and construction of knowledge.

This dissertation explores portfolio-based assessment, a method of alternative assessment, which requires students to compose a purposeful collection of work demonstrating their knowledge in an upper-level biology course. The research objectives include characterizing and contributing to the understanding of portfolio-based assessment in higher education, examining reflection and inquiry portfolio components, determining student knowledge of biological concepts, and investigating student integrative thinking through the transformation of reflections into concept webs.

One main finding includes the majority of reflections categorized as naïve or novice in quality. There was no difference in quality of reflections among biological topic. There was a relatively equal amount of high and low cognitive level questions. Students' knowledge of biological concepts significantly increased from the beginning to end of the course. Student written reflections were transformed into concept webs to allow for examination of student integrative thinking. Concepts, relationships, and interconnections in concept webs showed variation but declined by the end of the semester.

This study is one of the first examining portfolio-based assessment in an upper-level biology course. We do not contend that this method of assessment is the only way to promote student learning but portfolio-based assessment may be a tool that can transform science

education but currently the role of portfolio-based assessment in science education remains unclear. Additional research needs to be conducted before we will fully understand and be able characterize this type of assessment.

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DISSERTATION OVERVIEW

My doctoral research centers on undergraduate student understanding of biology as examined through an alternative method of assessment, portfolio-based assessment, in an upper-level biology course. The objectives of this dissertation were to add to the current understanding of portfolio-based assessment and examine student components of their portfolios to determine the quality of written reflections, the cognitive level of written questions, and knowledge of biological concepts. In addition, a model was developed to transform students' written reflections into concept webs to gain insight into student integrative thinking regarding biology.

This dissertation is presented in four chapters. The first chapter provides the background and foundation for this doctoral study and a literature review of the scientific ideas guiding this study. The two subsequent chapters describe separate studies written as journal articles. The second chapter examines the quality of student written reflections and cognitive level of student written questions, which were components from a type of portfolio-based assessment implemented in an upper-level biology course as well as the determined learning gains for biological concepts. Based on the earlier chapters, the third chapter examines whether evidence of integrative thinking exists in student written reflections through their transformation into concept webs. The fourth and final chapter is a summary of this study's findings, implications, explanation of limitations, and future research areas.

This dissertation was developed based upon the need for gaining a clearer understanding of an alternative method of assessment in biological science education. Currently, proponents of portfolio-based assessment highlight guidelines and make claims however, there is little empirical research examining portfolio-based assessment (Barrow 1993; Collins 1992; Paulson et al. 1991; Paulson and Paulson 1991) specifically, with few studies investigating the method of assessment in higher education and in a biology course for majors. This dissertation addresses the current void by examining portfolio-based assessment components of student portfolios from an undergraduate upper-level biology elective course and helps to characterize this method of assessment, its potential benefits, application, and implications.

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LITERATURE REVIEW

Introduction

Although studies, commentaries, and theoretical papers have been published, there is very little pragmatic research on assessment (Shepard 2000) particularly in biological sciences and higher education. Typically, studies and papers focused on assessment deal with the purpose, implementation, benefits, and concerns of each. This dissertation explores an authentic method of assessment through portfolio-based assessment that was implemented in an upper-level undergraduate elective course designed for biology and zoology majors.

Interest in science education research examining evidence of student learning at a deep level through assessment methods is growing. Discipline-based education researchers have recently highlighted a shift in the approach to assessment (AAAS 2009). Assessment is an integral part of education and can greatly influence student learning. Historically, assessment has aligned with the instructional paradigm and assessment of learning. Barr and Tang (1995) explain that a shift towards assessment for learning and the learning paradigm is currently underway that aligns with the growing body of research that is concerned with how students learn and students' role in the learning process.

Portfolio-based assessment is a method that highlights the shift currently taking place in education. The research relevant to identifying characteristics of portfolio-based assessment and the research pertaining to identifying and explaining influential factors of portfolio-based assessment will be detailed in this dissertation. I was particularly interested in the role portfolio-based assessment has in the process of learning for students. I examined the quality of reflections and inquiry from student portfolios, student knowledge of biological concepts, and student ability to integrate biological concepts.

How Students Learn

Piaget's (1969) work discussing the origins of intelligence addresses two essential elements. The first, assimilation, is a cognitive process by which new stimuli are placed into an existing schema allowing for cognitive growth. The second, accommodation, occurs when new schema are created or modified resulting in changes or the development of schema. Both assimilation and accommodation necessitate coordination, integration, growth, and development of cognitive structures. Ausubel (1968) built upon Piaget's work with assimilation when developing his theory of meaningful learning, which is the foundation of what is known as constructivism (Novak 1990b). Constructivist theory focuses on how individuals make sense of their experiences during the learning process and how people come to know (Bodner 2007). In constructivism, individuals are actively engaged in the learning process because the learner must pay attention to relevant content, organize it coherently, and integrate it with their existing knowledge (Mayer 1999). Constructivist learning theories outline that individuals actively build their own knowledge and that it is shaped by what a learner already knows (Shepard 2000). Students are an essential and active part of the learning process that form their own conceptions and explanations of experiences. Ausubel (1968) explains that acquiring knowledge and understanding involves an individual relating and reconciling new content within their existing knowledge framework. Assimilation explains how knowledge is structured and organized.

Piaget (1969) describes that the nature of intelligence matures through a variety of stages. The formal operation stage is the final stage described by Piaget, though not all individuals reach this phase (Wadsworth 1978). Individuals who have not reached the formal operational stage deal with problems concerning isolation and cannot integrate solutions with theory however, individuals that have reached the formal operational stage utilize theories to solve problems and may do so in an integrated manner, in addition, individuals can organize, reason, and generate hypotheses (Wadsworth 1978). Although Piaget's work was not developed from an educational perspective, it has important implications for student learning. Piaget (1969) explains that knowledge originates from experience and that active participation is necessary for cognitive development.

Historically, students have been viewed as empty vessels entering courses without any conceptions and waiting to be filled with knowledge. However, this is not the case. Knowledge is not discovered but is actively constructed with the individual doing the learning (Bodner 2007). Drawing on an individuals' own experience is vital to the learning process but Boud et al. (1985a) stipulates that experience by itself does not lead to learning and it is through reflection that an individual turns experience into learning. In fact, Dewey (1960) describes reflective thinking as the better way to think. Reflective thinking is highlighted by numerous attributes. When reflecting, individuals think critically about their thinking, may restructure their understanding and the way problems are framed, and make sense of the uncertain (Schön 1987). Dewey also explains that reflection in learning involves perceiving connections and relationships from experience, which can improve learning (Boud et al. 1985a). Boud et al. (1985b) explains that when reflecting, individuals engage in order to explore their experiences, which can lead to new understandings. There are multiple outcomes of reflection including synthesis, integration, and validation of knowledge as well as three main aspects of the process of reflection that include returning to experience, attending to feelings, and re-evaluating experience (Boud et al. 1985b). The latter involves individuals integrating knowledge into their existing framework (Boud et al. 1985b). Due to reflective thinking having such an important role in learning it should be reflected in course design.

Dewey (1960) also explains that reflective thinking involves doubt, hesitation, and perplexity where the individual must engage in inquiry to find resolution. Dewey (1960) places importance on inquiry, synthesis, and analysis in reflective thinking. Questions are a key factor in reflection because asking yourself questions is a property of a learner who is reflective and is a fundamental part of meaningful learning (Chin and Osborne 2008). Student questions represent a gap where students attempt to expand their knowledge; asking questions of oneself is an essential part of learning (Chin and Osborne 2008), and links thinking and learning (Cuccio-Schirripa and Steiner 2000). Questions that address ideas concerned with wonderment motivate students to develop explanations triggering deeper thinking (Chin et al. 2002).Inquiry is an integral part of reflection and is a way in which learning can be enhanced.

Students should be active in the learning process, construct their own knowledge (Shepard 2000; Barr and Tagg 1995; Engle 1994) and be involved in the assessment process (Buhagiar 2007). In order to learn, students must incorporate new information with their prior knowledge (Shepard 2000). Therefore, students must be able to link new information into their current mental model or framework. To learn, individuals construct their knowledge, which undergoes changes through reflection of their experience and involves making connections or integrating new content with existing knowledge (Mayer 1999). Curriculum, instruction, and assessment all contribute to the learning process. The relationship among these components is also crucial to how, what, and why students learn.

It is based on the contention that students should be actively engaged and construct their own knowledge that recent educational innovations are striving to change the approach to biology education. In 2009, The American Association for the Advancement of Science (AAAS) put forth its position about designing curriculum and approaching instruction in a way that emulates how scientific research is conducted. By doing so, students are provided with opportunities to construct knowledge based on their experiences allowing students to become active instead of passive participants in the learning process (AAAS 2009). Students who simply memorize facts are unlikely to make new discoveries and may not understand or accept previous scientific discoveries (Pennock 2005). By focusing on how scientific knowledge was discovered and having students' follow similar paths of reasoning, a deep understanding of the discipline may be fostered. In order to understand, students should be able to perform tasks beyond simply reproducing material such as making predictions and inferences. A student may have knowledge about a subject but that does not necessarily mean the student understands. For students to understand biology they are required to integrate concepts across organization levels, to synthesize, and analyze content (AAAS 2009). This can be a challenge in traditional science courses because there is an emphasis on factual knowledge while comprehension is minimized which can lead to student misunderstandings (Lord 1998).

When there is a focus on learning how to think (Henderson and Dancy 2007) and construction of knowledge (Huba and Freed 2000) student learning can be fostered. It is essential that support is given to students who pursue their own goals (Tagg 2003), a shift towards creative problem solving occurs (Henderson and Dancy 2007), and that students are engaged to think like scientists (Colburn 2004). Assessment can influence the development of student understanding (Entwistle and Entwistle 1992) and has the potential to improve learning (Shepard 2000). The relationship among curriculum, instruction, and assessment is crucial to how, what, and why students learn. In this dissertation, my focus is examining the role of assessment. Active construction of new knowledge can be fostered through assessment methods.

Assessment

Effective assessment is a process and is intimately linked to learning outcomes and instruction. Assessment provides a means to effectively measure student understanding of concepts (AAAS 2009) which determines whether curriculum is effective (Huba and Freed 2000) and therefore is a vital part of course design. Assessment involves “gathering, interpreting, recording and using information” from course activities completed by students (Lambert and Lines 2000) which then can be use to evaluate evidence of student learning with respect to learning goals (Crowe et al. 2008) to determine if students achieved the level of understanding desired (Huba and Freed 2000).

There are several key aspects of assessment. Assessment should provide the opportunity for feedback to be provided, revisions to be made based upon that feedback, and what is being assessed should align with learning outcomes (Bransford et al. 2000). Wiggins and McTighe (2005) explain that this backwards design is the best way to design a course because only when the desired understanding has been decided can the appropriate instruction and assessment methods be employed to achieve outcomes. Four main considerations need to be taken into account when determining assessment methods including what is being assessed, why, who, and how (Brown 2004). With regards to students, practitioners must take into consideration the learning process and students’ role within it.

A pillar of effective course design, assessment is an essential component to promote student learning. Wiggins and McTighe (2005) actually stipulate that the second part of curricular planning, after deciding learning goals, should be to determine assessment methods that allow goals to be properly evaluated. Therefore, assessment methods are second in importance only to learning goals (Crowe et al. 2008) and methods need to be employed that assess outcomes (Handelsman et al. 2004). If higher levels of understanding, retention, and critical thinking skills are desired, then a type of assessment that facilitates those characteristics should be utilized (Crowe et al. 2008; Shepard 2000; Angelo 1999). Due to the central role assessment plays in a course, special attention should be paid to what methods and how assessment is implemented. An imperative relationship exists between a student's experience with evaluation and assessment because it influences the approach a student takes when learning in the future (Struyven et al. 2005). Ultimately, assessment drives learning (Crowe et al. 2000) and may be the most significant factor influencing quality learning (Mintzes et al. 2001). Assessment can affect how students' approach a course (Gibbs and Simpson 2004) and influence what and how students learn (Briscoe and LaMaster 1991). Tagg (2003) explains that a deep approach to learning is active, holistic, and students are required to be mindful, connect new and previous knowledge, and question new ideas while making comparisons with old ideas. It is a meaningful learning and a deep approach to learning that higher education should strive to foster in students.

Assessment for Learning

The use of assessment methods is one of the most widely discussed topics in education (Michael 2006; Prince 2004). A shift in the view of assessment is occurring in education from assessment *of* learning to assessment *for* learning. Assessment of learning outcomes includes grading and reporting (Buhagiar 2007) and aligns with the purposes of summative assessment. Summative assessments were created mainly for reporting purposes (Schneinder and Shoenberg 2000) and to measure mastery of skills (Shepard 2000). Assessments of learning are interpreted to provide performance and cognitive information and are used to measure a construct, a conceptual model (Shavelson and Ruiz-Primo 2003). Summative assessments typically utilize traditional assessment methods, such as multiple-choice exams, tend to monitor progress (Bell and Cowie 2001), and are used to evaluate performance. These methods of assessment are typically high-stakes examinations that occur at the end of a course unit (Wood 2009). Historically, assessment of learning methods such as traditional and standardized exams have been widely and regularly used. Pellegrino et al. (2001) explains that standardized tests were developed as a means to quickly educate a booming population efficiently, monitor school systems, and classify students. These types of methods still predominate today and emphasize facts, definitions, skills, and knowledge while limiting the richness of knowledge and cognition that can be measured (Pellegrino et al. 2001).

Assessment for learning however occurs during the learning process, strives to improve student learning through engagement, and focuses on student ownership of learning (Willis 2007). Assessment for learning emphasizes the importance of questions, nature of feedback, peer and self-assessment, and asking questions of oneself (Black et al. 2002), is informative, encourages students to review their own learning, and can increase student motivation (Willis 2007). Assessment for learning is also characterized by frequent testing and had a goal of monitoring understanding (Wood 2009). In addition, in assessment for learning the purpose needs to be clear, methodology needs to be valid, feasible, and transparent, and the instruments used need to be reliable (Race 1995). By utilizing ongoing assessment, the instructor and student are able to monitor progress to support growth. Perkins (1993) also argues that assessment should emphasize feedback and reflection. In assessment for learning, evidence of student learning should attend to the needs of students (Buhagiar 2007).

Another essential aspect of assessment for learning is the role of the student in the learning and assessment process. Brown (2004) explains that in order to be sure assessment is part of the learning process; assessment needs to be learner-centered. Therefore, students need to be involved in the process of assessment, which may be done through choice, ownership, and self-assessments (Davies and Le Mahieu 2003). Assessment for learning should be formative providing instructors and students with feedback (Bell and Cowie 2001). Formative assessment is low-stakes (Buhagiar 2007) yet the feedback has the capacity to produce learning gains (Black and William 1998b; Wood 2009) because it can provide information that a student can use to improve (Tagg 2003).

Shepard (2000) argues that if assessment for learning is going to be pursued than we must understand the negative role accountability and externally imposed tests have on classrooms. It is vital to remember that tests can be corrupt (Shepard 2000), completion of tasks may actually have little to do with whether a student understands concepts (Vitale and Romance 2005), and assessments may not effectively measure what is intended. A change in the view and purpose of assessment is occurring. Assessment is a necessity of education and the discourse surrounding assessment methods has been sparked because of the influential role assessment can have on student learning.

Not all assessments, even those that strive to meet the tenets of assessment for learning are quality assessments. Building on the assessment triangle introduced by Pellegrino et al. (2001), Shavelson and Ruiz-Primo (2003) developed an assessment square as a framework to develop and evaluate the quality of assessments (Figure 1). Within Pellegrino et al.'s (2001) model, the corners include observation, interpretation, and cognition. Pellegrino et al. (2001) explains observation provides the evidence of student competence, while interpretation makes sense of that evidence and cognition includes the students' beliefs about representing knowledge The corners of the square represent the four key elements that underlie assessment. The

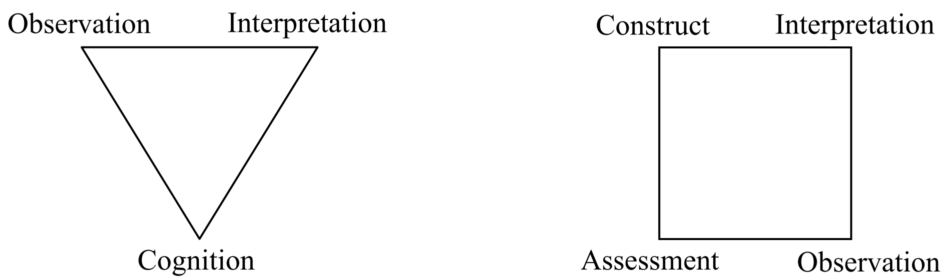

Figure 1. The assessment triangle (Pellegrino et al. 2001) and assessment square (Shavelson and Ruiz-Primo 2003).

assessment square however, includes four corners including: construct, assessment, observation and interpretation (Shavelson and Ruiz-Primo 2003) (Figure 1). The construct term in the square corresponds to cognition in the assessment triangle (Shavelson and Ruiz-Primo 2003). Assessment is the “physical manifestation of the working construct definition” and allows behavior to be elicited, observed, and described (Shavelson and Ruiz-Primo 2003). Observation involves “collecting and summarizing students’ behavior in response to the assessment” while interpretations analyzes “the validity of the interpretations from an assessment to the construct” (Shavelson and Ruiz-Primo 2003). This framework provides a model in which assessment can be evaluated and can have implications for analyzing assessments (Shavelson and Ruiz-Primo 2003). Assessment cannot be effectively developed or implemented without considering these features.

Portfolio-Based Assessment

What is Portfolio-Based Assessment?

In portfolio-based assessment, student learning is evaluated by the evidence from a purposeful collection of student’s work that represents achievement, progress, growth, and reflection (Paulson et al. 1991) with portfolios being described as containers of evidence (Collins 1992b). Vitale and Romance (2005) expand on these definitions explaining that students must complete activities where they use and apply their knowledge to demonstrate their understanding. Therefore, in order to produce a portfolio a student often needs to realize what they have learned and be able to demonstrate it (Jarvis et al. 1998). Paulson et al (1991) describe that a portfolio is only a portfolio when students are a participant in the process of assessment (Paulson et al. 1991).

Portfolio-based assessment is an authentic method (Wiggins 1989) and establishes a learning environment where students construct their own meaning (Paulson and Paulson 1994b). After constructing their own understanding (Tang et al 1999), it is the students' responsibility to select and provide evidence of their learning. Therefore, it is the students' responsibility to select and assemble their own portfolios facilitating an active role in the assessment process and promoting active learning (Kish and Sheehan 1997). Portfolios "provide a more equitable and sensitive portrait of what students know and are able to do than traditional assessments" (Herman and Winters 1994).

It is essential to view portfolio-based assessment under the constructivist paradigm because efforts to apply other paradigms may impose meanings that differ from those of the student (Paulson and Paulson 1994b). However, portfolios in some instances have been used for measurement where activities are completed for a grade or score rather than to promote reflection (Serafini 2000) which is not in keeping with the purpose of this method of assessment. Portfolio-based assessment's purpose is to provide students' with opportunities to be actively engaged in the learning process and construct their own knowledge.

Historical Perspectives

Portfolio-based assessment has been implemented in a variety of situations and can be implemented in specific courses or classes, over multiple courses or years to assess individual students, and for curriculum or program effectiveness. States such as Vermont have relied heavily on portfolios to assess student education statewide (Koretz et al. 1993). In fact, portfolios have been widely used in K-12 education in the United States and attempts have been made to develop portfolios into systems of assessments (Herman and Winters 1994). Portfolio-based assessment was first developed in school systems as a mechanism to promote reflective thinking (Snadden and Thomas 1998) and as a way to assess composition and writing in K-12 education (Herman et al. 1993). More recently, portfolio-based assessment has been implemented in elementary mathematics (Clarkson 1997) and secondary science education (Dickson 2004; Butler 1997).

Although portfolio-based assessment has been less common in higher education (Zubizarreta 2009) its utilization is exploding. Portfolio-based assessment has been utilized in some undergraduate majors (Fitzsimons and Pacquaino 1994; Prince 1994), programs (Ashelman and Lenhoff 1994), and online learning (Reeves 2000). Portfolio-based assessment has also been introduced into composition and writing in higher education (Hileman and Case 1991; Belanoff and Elbow 1986), teacher education (Zeichner and Wray 2001; Curry and Cruz 2000), undergraduate second language education (Yang 2003), and medical fields (Gadbury-Amyot et al.2003). Portfolio-based assessment is also utilized for different purposes such as assessment of competence (McMullan et al. 2003), proficiency testing, program assessment, as classroom portfolios (Belanoff and Dickson 1991), and in a summative manner (Davis and Ponnamperuma 2005). In medical education for example, portfolio-based assessment has been used as a summative assessment to assess personal and professional development in medical students (Gordon 2003), and as an assessment of competence in nursing students (McMullan et al. 2003). Portfolio-based assessment is less common in science fields but it has been implemented in chemistry at the secondary education level (Phelps et al. 1997) however, portfolios in this case were low stakes. Portfolio-based assessment has also been implemented in chemistry at the undergraduate level but the in this case the portfolio's purpose was for programmatic assessment (Roecker et al. 2007). Although portfolio-based assessment has numerous possibilities (Collins 1992a), its utilization in science disciplines in higher education remains infrequent.

Why Use Portfolio-Based Assessment?

Portfolio-based assessment has been described as linking learning as assessment (Davis and Ponnamperuma 2005) as students are essential and active participants in both the process of assessment and their own learning. The method of assessment implemented can also influence students' approach to learning. Tang et al. (1999) found when examining preparation strategies of students, those who were assessed using exams tended to memorize facts while those evaluated using portfolio-based assessment were able to summarize, relate information, and adopted a deep learning approach.

Portfolio-based assessment allows for information about student learning to be gained, progress to be observed, and provides opportunities to detect how students develop knowledge (Dickson 2004; Burch 1997). Portfolio-based assessment provides an opportunity to discuss achievement at numerous levels and when implemented appropriately can give instructors valuable information about the progress of student learning (Bransford et al. 2000). Uncovering preconceptions or alternative conceptions provides insight into how students' understanding develops and can have implications for instruction thereby linking instruction with assessment.

Portfolio-based assessment provides the means for ongoing assessment as students have the ability to contribute to their portfolios on a regular and frequent basis. This is essential from a student and practitioner perspective. When students have the ability to revise their portfolio students can become more engaged and active in the assessment process (Phelps et al. 1997) an attribute of assessment for learning (Willis 2007). Practitioners are able to monitor progress (Davis and Ponnamperuma 2005) and provide feedback, an essential component of effective learning (McTighe and O'Connor 2005). This makes portfolio-based assessment a strong formative tool as well, a key principle of assessment (Bransford et al. 2000).

Portfolio-based assessment can facilitate students' ability to analyze, conduct research, make decisions (Wenzel et al. 1998), collaborate (Tiwari and Tang 2003), and think critically (Davis and Ponnamperuma 2005). Portfolios give students an opportunity to see their own progress and to realize areas needing improvement (Wright 2007). Portfolio-based assessment encourages student participation (Mullin 1998) and supports the development of critical thinking (Kish and Sheehan 1997). Additionally, students are able to take ownership of their learning (Dickson 2004; Ashelman and Lenhoff 1994; Paulson et al. 1991), become self-directed (Campbell et al. 2000; Paulson et al. 1991), accountable and responsible for their own learning (Davis and Ponnamperuma 2005). Portfolio-based assessment provides an environment in which students are engaged, integrate, apply (Tang and Biggs 1998), and reflect on knowledge (Tang et al. 1999). Reflection is an essential aspect of learning that portfolio-based assessment helps to promote (Davis and Ponnamperuma 2005; Tang et al. 1999). The premier benefit associated with portfolio-based assessment is reflection.

Components

The components, activities, contents, or tasks included in student portfolios are dependent on its purpose. The components that portfolios are comprised of are dynamic by their nature. The diversity in components or tasks allows for the potential for alignment with diverse learning outcomes and for a more comprehensive approach to assessment. For instance, in writing portfolios writing samples are included (Hileman and Case 1991) but depending on the portfolio's purpose components could include reading comprehension, scientific reasoning, practical procedures, evaluations (Davis and Ponnamperuma 2005), essays (Dickson 2004), and laboratory proficiencies (Roecker et al. 2007).

Even though diversity exists in portfolio-based assessment one component should be universal to the assessment method, reflection. Portfolios should be reflective (Lynch and Shaw 2005) and the use of reflections is an essential commonality of portfolio-based assessment (Campbell et al. 2000) that analyzes learning experiences (McMullan et al. 2003). This component is specifically vital to include in portfolios because reflections can lead to deep and long-term learning which can ultimately contribute to a better understanding (Williams 1985). Reflections can be helpful for students to synthesize their learning as well as to review their experiences (Brown 2004) both of which are vital in constructing knowledge. Reflections are an essential component of portfolio-based assessment yet differences exist in the type or quality of reflecting being engaged in. When truly thinking reflectively one is able to restructure what he or she is doing and why they are doing it (Schön 1987), have the opportunity to develop ideas, and make connections to previous knowledge (Killion 1999). In reflections, synthesis of learning can be fostered (Brown 2004) and connections are built that can foster meaningful learning. Although there are a wide variety of components that can be included in portfolio-based assessment there is a lack of components designed to promote and assess student inquiry and integrative thinking.

Issues and Barriers

Even with numerous benefits associated with portfolio-based assessment there is little evidence aside from those from practitioner reports that demonstrate learning gains (Black and William 1998a). Additionally, dissidence exists for a number of claims made about portfolio-based assessment. For instance, Terwilliger (1997) claims that traditional assessment methods are not automatically less authentic than portfolio-based assessment, that basis for assessing growth in portfolio-based assessment is flawed, and that portfolio-based assessment is not suited for all subjects and all grades.

Reliability and Validity

Davis and Ponnampermua (2005) contend that inter-rater reliability related to portfolio-based assessment remains inconclusive. When examining portfolio-based assessment conducted statewide in Vermont, the portfolios from fourth and eighth graders produced for writing and mathematics, the reliability coefficients were found to be low ranging from 0.23-.0.57 (Koretz et al. 1993). It is possible to achieve high reliability though. A study examining writing portfolios produced by third and fourth graders had reliability coefficients that ranged from 0.76 to 0.94 (Herman et al. 1993). It should be noted that general competence scores could not be determined in this study though because raters found it difficult to assess student portfolios based on subscales of their rubric (Herman et al. 1993). In addition, a study by Naizer (1997) examining performance portfolio-based assessment from pre-service teachers found that rater variances were very small. In a similar study, Stuessy and Naizer (1996) established 75% rater agreement when two raters scored twelve student portfolios.

Due to portfolio-based assessment's ability to assess real-life performance in utilizing both qualitative and quantitative assessments in a variety of settings it has high face validity in that it appears to measure what is suppose to and "has potential for high content validity" (Davis and Ponnamperuma 2005). In evaluating validity of performance portfolio-based assessment for pre-service teachers, Naizer (1997) established content validity due to a variety of instructors being involved in the development of the course. Gadbury-Amyot et al. (2003) established high validity and reliability when examining portfolio-based assessment in an undergraduate dental hygiene program. In this study, raters evaluated thirty-two components grouped into seven subscales. The differences could be attributed to the faculty raters being involved in the development of competencies (Gadbury-Amyot et al.'s 2003). Vermont attributes low reliability to unclear or inconsistent terminology in scoring rubrics, insufficient training, and that non-standardized implementation, meaning students performed different activities under different conditions (Koretz et al. 1993).

Herman and Winters (1994) explain that a useful approach to determining validity of portfolio-based assessment is to examine the relationship between student portfolios and other indicators of student performance or achievement. They presume if there is a weak or no relationship between student portfolios and other valued measures then they are measuring different capabilities. Gadbury-Amyot et al. (2003) found when examining the relationship between student portfolios and the Central Regional Dental Testing Service (CRDTS) examination the relationship was weak and insignificant. One reason why a weak relationship was found in this study could be that the approach of comparing student portfolios assumes that the other measure(s) are good which can be of particular concern as interest in alternative assessments has stemmed from distrust of traditional methods (Herman and Winters 1994). The results from Gadbury-Amyot et al. (2003) may not be surprising either as Paulson and Paulson (1994a) expect academic achievement and the quality of a student's portfolio to be unrelated as the skills associated with each differ. In addition, the methods employed to examine portfolio-based assessment in studies are specific to a particular course and learning outcomes.

Paulson and Paulson (1991) are not so quick to dismiss disagreement between raters as negative either because disagreement may reveal that the same criteria are being interpreted differently, that different information is being attended to, and it may be more valuable for students for this disagreement to be discussed. McMullan et al. (2003) suggests that when assessing portfolios evaluating rigor of qualitative research is more appropriate than research focusing of criteria of validity and reliability. When reliability is a goal, tests that produce high reliability are produced (Paulson and Paulson 1991) and although traditional exams may be high in reliability but have a reduction in authenticity (Paulson and Paulson 1990). Paulson and Paulson (1994a) recommend being cautious when considering questions related to reliability and validity of portfolio-based assessment because portfolios are not tests of achievement and therefore it may be necessary to rethink the rules that oversee traditional tests and whether they are applicable to portfolios. In may be that when it comes to portfolio-based assessment different standards of reliability are necessary (Paulson and Paulson 1990).

Other Issues

Other issues exist concerning portfolio-based assessment besides reliability and validity. Portfolios can be additionally cumbersome to assess since forming judgments over time and from multiple sources of evidence can be difficult due to either inconsistencies or components being disconnected (Harlen 2008). All of these require the instructor to be dedicated, organized and self-disciplined (Wright 2007). Implementation of portfolios therefore requires a great deal of learning by the instructor (Michael 2006) and investment to reduce concerns over their logistics, interpretation, reliability, and validity (Yang 2003). This begs the question of whether portfolio-based assessment is practical and feasible. In addition, educators may have difficulty relinquishing control over evaluation to their students (Gadbury-Amyot et al. 2003)

Concerns over implementation from the student perspective need to be considered as well. Students may be hesitant to be responsible for their own assessment (Gadbury-Amyot et al.

2003). When portfolios are used as a summative form of assessment students as well may be reluctant to reveal their weaknesses (Davis and Ponnamperuma 2005). Tang et al. (1999) found that compared to traditional exams, students were less positive about their portfolio-based assessment experience, do not always think that portfolio-based assessment helps promote their understanding of content, and may not enjoy this type of assessment method. Cheating can also be a concern because it can be difficult to verifying whether students are submitting their own work (Davis and Ponnamperuma 2005).

Advice and Guidelines

As with all assessment methods there are numerous aspects to consider before implementation. Portfolio-based assessment needs to be critically considered and developed. Numerous studies and commentaries provide advice and guidelines concerning the implementation of portfolio-based assessment. It is unavoidable, that no matter who is assessing student portfolios, judgment will enter into the assessment process (McMullan et al. 2003). Therefore, practitioners need to standardize course content and develop scoring rubrics. Herman and Winters (1994) stipulate that to have a consensus, rubrics must have clear articulated criteria, reflect shared values and experiences, and effective training concerning rubrics are necessary. All of these tasks require an extensive investment of time and effort.

Besides the development of scoring rubrics, Collins (1992a) explains that three roles must be considered: who designs, who develops, and who assesses the portfolio. McMullan et al. (2003) in a review of portfolio-based assessment stipulate that an essential component of a portfolio is the student-teacher relationship and that explicit guidelines are necessary concerning the construction of portfolios. Criteria and standards need to be clear so students can make judgments about their portfolios (Paulson and Paulson 1991). Collins (1992a) poses multiple questions to ask before implementing portfolio-based assessment including what the portfolio will be evidence of, what will count as evidence, and how much evidence should be included.

Paulson and Paulson (1994a) take the advice concerning portfolio-based assessment one-step further by providing a guide for judging student portfolios. The model presented, a Cognitive Model for Assessing Portfolios (CMAP), provides educators with a way to view and think about portfolio-based assessment. Three major categories or dimensions are presented for consideration: the stakeholder, the process or activity, and history. The stakeholder represents groups that have interest in the portfolio such as students and the practitioner. The activities dimension includes the rationale or what the purpose is, the intention of the portfolio, and the contents. Lastly, the historical dimension considers what is occurring over the course or class. The role of students, a stakeholder, may be of particular importance. Naizer (1997) suggests that when students were involved in the scoring process, the experience helped in the development of future activities and it may be a way to help alleviate the extensive time commitment required by practitioners. In the end, numerous advice and guidelines have been established concerning portfolio-based assessment however, the majority of studies are anecdotal or observational.

Limitations and Weaknesses

With all the studies investigating portfolio-based assessment, few explicitly describe the process of why and how portfolio-based assessment was implemented and there has been little empirical research conducted. In a review by Herman and Winters (1994), over ten years of studies investigating portfolio-based assessment were examined but only seven articles were found to have reported data or used acceptable research methods. The results from this study align with studies that are described in this literature review, which typically explain the rationale behind portfolio-based assessment, provide recommendations, or describe advantages and disadvantages. Numerous studies address guidelines or considerations about portfolio assessment its components (Fernsten and Fernsten 2005; Davis and Ponnamperuma 2005; Kuhs 1994). As Herman and Winters (1994) explain, very few studies pay attention to "technical quality, to serious indicators of impact, or to rigorous testing of assumptions."

It should be noted that not all studies fall into this category. Some studies do provide scoring rubrics; however, when these rubrics are provided the studies often do not provide an explanation of development, application, or examples (Dickson 2004; Naizer 1997; Stuessy and Naizer 1996; Kuhs 1994). For instance, Naizer (1997) who assessed pre-service teacher student portfolio performance, states that a rubric was adapted from a previous study and employed with slightly different criteria but does not provide an explanation as to why or how the rubric was altered or applied. When examining the rubric from the prior study, Stuessy and Naizer (1996), the study provided again no explanation as to how the rubric was developed or applied.

Others may go one-step further and provide examples (Collins 1992b) however; there is a consistent lack of information about methodology and evidence with the focus instead being on describing the process of implementing portfolio-based assessment and its potential possibilities or restrictions. The advice and guidelines provided in these studies also have limitations. Yang (2003), who implemented portfolios in undergraduate second language education, provided results primarily based on student reactions and opinions. This study does not include assessment criteria nor does it demonstrate how students' portfolios were explicitly assessed. In addition, a substantial portion of criteria is based on completion (i.e. "have you included all the required materials in the portfolio"). It is difficult to determine if appropriate considerations or guidelines about using portfolio-based assessment are followed as few studies articulate a detailed methodology about how portfolio-based assessment was developed and implemented.

Portfolio-based assessment often uses criterion-based rubrics and promotes ongoing assessment, which can have implication for grading. Wiggins and McTighe (2005) explain that often grades are provided without clear criteria and scores are typically averaged over the course. Clear standards are necessary to achieve high reliability and validity but when scores are averaged, we may lose one of the key advantages of why portfolio-based assessment is utilized, how student understanding grows or progresses. However, advice from other studies does not necessarily follow this contention. Paulson and Paulson (1994a) suggest using their CMAP model to assess portfolios as a whole, but portfolios often are comprised of multiple activities, as they are a multidimensional assessment method. This may require the development and use of multiple rubrics. When assessing student portfolios, which are composed of numerous components, only as a whole, characteristics or attributes from specific components may be lost.

Conclusion

As this literature review describes, portfolio-based assessment has been limited in its implementation. Portfolio-based assessment has not utilized widely in higher education and when done so, it is primarily found in teacher education and medical fields. Few studies have examined portfolio-based assessment in science fields and those that have done so are often conducted to evaluate portfolio-based assessment in a programmatic and summative context while few examine portfolio-based assessment as a formative assessment tool. In addition to reflections, portfolio-based assessment contains other components to demonstrate evidence of student learning. The components included however should align with learning outcomes. Even with the vital role student inquiry can have on learning, this has not been integrated with portfolio-based assessment previously nor has using the reflections from portfolio-based assessment to examine student integrative thinking. Portfolio-based assessment may be a way to encourage and assess reflection, inquiry and students' ability to connect and recognize relationships in content in an undergraduate biology course.

Portfolio-based assessment highlights characteristics inherent to assessment for learning. As with any type of assessment, there are concerns that need to be considered before implementation. Practitioners must determine what their learning outcomes are for students, why they are assessing students, and then consider an appropriate assessment method in order to help promote student learning. In the case of portfolio-based assessment, the specific components that will be included in student portfolios and what will count as evidence also need to be considered. Even as the benefits of portfolio-based assessment are beginning to be uncovered, empirical research is necessary in order to understand this assessment method and attempt to overcome limitation and weaknesses from other studies. Research investigating the implementation of portfolio-based assessment as a formative form of assessment, in an upper-level undergraduate course, or in biological sciences is rare. However, portfolio-based assessment has potential to transform assessment and this is only beginning to be uncovered.

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PAPER 1. MEASURING STUDENT UNDERSTANDING IN A PORTFOLIO-BASED COURSE

Abstract

The use of assessment methods is a widely discussed topic in education. Exams that are commonly used however may not necessarily assess student understanding at a high cognitive level. By implementing alternative assessment methods, instructors can influence student learning. Portfolio-based assessment is a purposeful collection of student work that represents achievement, progress, growth, and reflection. In this study, we examined student portfolio-based assessment, which has been implemented in an upper-level biology course. The two sections of the portfolios analyzed were students' written reflections and questions from the inquiry section. Students' knowledge of biological concepts was also assessed on an initial and final assessment. Although initially poor, students' knowledge increased substantially on the final assessment. The majority of student reflections were found to be naïve or novice in quality and no significant difference was found in quality between topics covered. Variation however exists between topics on which students chose to reflect. In the inquiry section, students posed an almost equal amount of higher and lower cognitive level questions. This study is one of the first examining portfolio-based assessment in an upper-level college science course. Implementation of portfolio-based assessment may be a method to improve student understanding of biological concepts.

Introduction

One of the most widely discussed topics in education is the use of traditional and non-traditional assessment methods (Michael 2006; Prince 2004). Although most universities place importance on students' developing a broad understanding of content while becoming independent thinkers, the majority of courses are taught and assessed in ways that focus on specific detailed knowledge (Taras 2002) with the most common assessment method being exams. Most exams focus on facts instead of comprehension contributing to student misunderstandings in biology (Lord 1998) and biology is not immune to this trend. Students struggle with transforming knowledge across subject areas (Perkins 1993). If higher levels of understanding, retention, and critical thinking are desired, then assessment to promote those characteristics should be utilized (Crowe et al. 2008). Innovative methods are needed to assess outcomes (Handelsman et al. 2004). Assessment is one way instructors can significantly influence student learning (Crowe et al. 2008), especially, alternative assessment methods.

Alternative assessments are any methods that are not multiple-choice exams and serve to integrate learning and assessment while promoting future learning (Buhagiar, 2007). Alternative assessments emphasize that knowledge has multiple meanings, learning is an active and collaborative process, assessment should facilitate learning, and traditional assessment is subjective and value laden (Anderson 1998). Portfolio-based assessment highlights the characteristics of alternative assessment.

Concerns About Using Portfolio-Based Assessment

Incorporating portfolio-based assessment into courses is challenging for numerous reasons some of which include interpretation of components, reliability, validity and logistics as well as the time investment for both students and instructors (Yang 2003). To implement portfolio-based assessment an instructor must develop necessary components based on the purpose or goal of the portfolio as well as rubrics since effective scoring can be problematic (Collins 1992). These concerns require the instructor to be dedicated, organized, and self-disciplined (Wright 2007). Implementation of portfolio-based assessment, therefore, requires a great deal of learning by the instructor (Michael 2006). It has been suggested that portfolio-based assessment content should be limited and one-dimensional allowing for reliable evaluation because when topics increase, consistency and reliability can be lost (Wright 2007). As with all types of assessment, the completion of portfolio-based assessment tasks may have little to do with whether students understand content (Vitale and Romance 2005).

Reasons For Use

Student learning in portfolio-based assessment is evaluated by a purposeful collection of work representing achievement, progress, growth, and reflection (Paulson et al. 1991). Vitale and Romance (2005) expand this definition explaining that students complete activities using and applying knowledge to demonstrate understanding. To produce a portfolio, students often need to realize what they have learned and be able to demonstrate it (Jarvis et al. 1998).

Portfolio-based assessment allows students to be evaluated in a broader context (Paulson et al. 1991) and individual differences can be taken into account while emphasizing improvement, effort, and achievement (Yang 2003). Portfolio-based assessment allows an opportunity to observe learning and gain insight into how students develop knowledge (Burch 1997; Dickson 2004). Instructors can discover potential alternative conceptions allowing for appropriate changes in instruction to help promote future learning. Portfolio-based assessment fosters opportunities to illustrate achievement at numerous levels and when implemented appropriately can give instructors valuable information about the progress of student learning (Bransford et al. 2000). Additionally, portfolio-based assessment offers ongoing assessment, which has been noted as necessary to gain understanding (Perkins 1993). Portfolio-based assessment gives students an opportunity to see their own progress and realize areas needing improvement (Wright 2007). Student reflections are specifically vital to increasing understanding (Campbell et al. 2000) as reflections can lead to deep long-term learning ultimately contributing to better understanding (Williams 1985). Promoting critical thinking skills is a goal of science education (Bailin 2002) and portfolio-based assessment gives students an opportunity to critically think about material.

Portfolio-based assessment has been implemented frequently in elementary (Clarkson 1997) and secondary education (Butler 1997; Dickson 2004; Stecher 2004). Although it has been less common in higher education (Zubizarreta 2009). Portfolio-based assessment has been utilized in some undergraduate majors (Fitzsimons and Pacquaino 1994; Prince 1994), programs (Ashelman and Lenhoff 1994), online learning (Reeves 2000) and used as a means of teacher assessment (Curry and Cruz 2000). Portfolio-based assessment is versatile with numerous possibilities (Collins 1992) and is slowly becoming part of science education at the undergraduate level. Portfolio-based assessment has been implemented into science majors such as chemistry with beneficial outcomes (Roecker et al. 2007) however; portfolio-based assessment is still infrequent in sciences and is specifically rare in biology.

There are numerous possible components of portfolio-based assessment and applications and this study was developed to investigate two aspects of portfolio-based assessment. The instructor switched from traditional exams due to dissatisfaction of student understanding and measuring discrete fragments of knowledge. Our analysis is independent of the course instructor and provides an external measure of quality. Therefore, the purpose of our study was to examine student portfolio-based assessment components that were implemented into an upper-level science course to promote meaningful learning.

Methods

Research Context

Portfolio-based assessment was implemented in a three-credit, upper-level science course, that met three times weekly and covered physiological mechanisms underlying life-history trade-offs and constraints in an ecological and evolutionary context. The course focuses on a variety of main topics including evolution, energy acquisition, life history, metabolism and scaling, homeostasis and allostasis, and energy allocation to growth, reproduction and self-maintenance (Appendix A). The course emphasized building upon previous coursework to understand complex concepts and connections across biology. Instruction was lecture-based with students required to develop a *Portfolio-of-Understanding* (Appendix B).

The Portfolios-of-Understanding were composed of four components: reflection, inquiry, lecture notes, and primary literature all of which were designed by the instructor. Working within the context of the course two aspects of the Portfolio-of-Understanding were analyzed, the student written reflection and inquiry sections. Minimum weekly contributions to each section were required; therefore, each student submitted 14 inquiry questions and one-page reflections. Through reflections, students had opportunities to reflect on course content, link material to previous experiences and interests, and provide material from outside sources such as primary literature and other coursework. Students were encouraged to revisit and expand previous reflections as their understanding developed (Appendix B). The inquiry section required students to pose questions, create hypotheses or make predictions, and had an opportunity to attempt to answer their own questions (Appendix B). Portfolios-of-Understanding were maintained electronically. The instructor assessed each student’s work four times to provide guidance, feedback or pose additional questions for response.

In order to gain a clearer picture of student knowledge of concepts, students completed an initial assessment (Appendix C) on the first day, composed of open-end questions designed to elicit student knowledge of biological concepts (e.g. acclimation, genotype, and symmorphosis etc.). At the end of the course, students completed a final assessment, the take home final, which included the same open-end questions about biological concepts as on the initial assessment. Although they differed in format, both assessments were designed to measure student knowledge of biological concepts. Additionally, they were not part of the regular weekly contributions of the portfolio, but were required by the instructor to be submitted as part of the portfolio documents after completing them.

Twenty-nine of the 38 undergraduates registered allowed access to their coursework, while 28 completed the course. Senior zoology majors accounted for 90% of the students. There was an equal distribution of males and females (M = 15; F = 14). IRB approval was #SM10164 (Appendix D).

Data Collection

We developed an ordinal scale rubric from student responses to measure student knowledge of biological concepts on both the initial and final assessment (Table 1). For the

Table 1. Coding rubric for initial and final assessment and examples of rubric application to student written responses.

Coding Rubric	Coding Explanation	Initial Assessment Osmosis Example
Non-Response	--	--
Naïve	Response is incorrect or is too vague to determine if correct	"*To get something by touching the thing that has it*" – Student 5
Novice	Response contains both incorrect and correct statements and may be incomplete	"*Fluids traveling across a membrane*" – Student 16
Intermediate	Response is correct but is not complete	"*Diffusion of water*" – Student 24
Advanced	Response is correct and complete	"*The diffusion of H_2O through a semi-permeable membrane*" – Student 26

purposes of analysis, two researchers independent from the course individually coded initial assessment responses. The researchers discussed any disagreement in scores until each was resolved. Then one researcher continued to code the final assessment. If student responses contained components that fit multiple areas of the rubric, they were coded into the category to which they most closely aligned (For narrative explaining process of coding initial and final assessment see Appendix E).

Reflections were coded for topic then for quality and scored on an ordinal scale. The reflection rubric emerged after analyzing literature evaluating reflections and rubrics. The rubric consists of six levels for a reflection and each has clear criteria (Appendix F). These criteria were developed based upon factors deemed part of quality thinking, such as ability to make valid inferences (Bailin 2002) and course requirements (Appendix B). For example, a goal of the course is to foster student growth in understanding the interconnectivity of biological fields and concepts. Examples of how reflections were coded are outlined by excerpts in Table 2. (For narrative explaining process of coding reflection examples from Table 2, see Appendix G). When reflections contained aspects from multiple rubric categories they were coded into the category they best fit. Examples of student reflections containing aspects of different categories of the reflection coding rubric could include (1) a reflection where a student applied concepts to new situations but draws conclusions based on preconceptions or (2) if a student's reflection was largely composed of definitions but primarily literature was used to provide evidence of those definitions. Inquires were coded using Bloom's Taxonomy (Lord and Baviskar 2007; Table 3) to determine student level of thinking. If questions embodied components from different levels they were coded at the highest level the question reached. Non-responses were not included in statistical analysis as well as students who did not complete both the initial and final assessment

Table 2. Application of coding rubric for student reflections based excerpts.

Coding Rubric	Excerpts from Students' Written Reflections
Inadequate	"*Coming into class I was a little apprehensive because of the course name 'Physiological Ecology'. I saw ecology and started to get worked up a little because I didn't really enjoy nor have an interest in Bio 322 ecology."* – Student 7
Naïve	"*Constraints provide restrictions or limitations to the possibility of adaptations. There could be genetic constraints, developmental, mechanical, phylogenetic, and physiological constraints*." – Student 10
Novice	"*I also wanted to reflect on a method that seemed to strike me as mostly useless. This was would be the "energy in – energy out = energy used" method. This is such a hard to do method I don't understand where it could be useful in biology. You cant [sic] do it with growing animals because not all of the energy would be put out, some would be used for growth. Also I would think that there are several other exceptions that would make this way to tricky to use*." – Student 14
Intermediate	"*…I feel using the term allostasis is a lot like using the term regulator. Allostasis is the concept of process of bringing the body back to normal homeostatic ranges after being exposed to a stressor. The adaptive ability/quality that this concept of allostasis possesses within one's own body is truly remarkable. The Romero, L.M. et al. paper that we read in class provided a great model and usable definitions that highly aided in my understanding of the subject. Now if I were to apply this concept of allostasis towards reproduction, one can see that many of the systems that we have covered thus far in class are highly interrelated. For example, consider those individuals who are income breeders, that is, they rely on foraging for food and thus acquire energy concert with their reproductive seasons. If an individual was about half way into its breeding season and suddenly its resource availability plummeted, that individual I would undoubtedly become stressed out*." – Student 13
Advanced	"*When you first think of allostasis you think about trying to maintain what you have at any given time. I think a better definition is one we discussed later which is fitness under natural selection, but is this all that allostasis covers? I think fitness and natural selection are great starting points for a further in depth look at what allostasis covers. I came across an article that is looking at linking a form of alcohol tolerance and dependence to allostasis. This article is focusing on the idea that allostasis has something to do with ones tolerance to alcohol. Just thinking about this makes sense. If one were to drink copious amounts of alcohol then they would need to be able to survive and adapt in some ways, so why not be able to consume larger amounts with no effects. They also are trying to link this to why dependence and allostasis are linked. This also makes sense to me. Like a drug you can have withdraws from not having alcohol in your system. This is your body telling you that you need more alcohol to maintain allostasis. Where as I hate to agree to this, but alcoholism is a very serious disease. The allostasis that is taking place is exactly what we are defining. Both a dependence and a tolerance are clear ways to adapt to survive in a way. That is why treatment is so hard to get through for patients in rehab. They are so used to adapting one way to fit allostasis that it is hard to learn another way when there are no good side affects afterward*." – Student 27

(N=4). Therefore, initial and final assessment scores were matched. Statistical analysis was inappropriate when comparing initial and final assessments for specific concepts due to an inadequate number of student responses on the initial assessment Initial and final assessments were therefore collectively compared by averaging individual student scores. Gain in

Table 3. Coding rubric for inquiry section and examples of how rubric was applied to student questions.

Bloom's Taxonomy Category	Examples from Students' Inquiry
Knowledge	"*How many offspring do they have?*" – Student 1
Comprehension	"*Describe the difference between the upper critical temperature and the upper lethal temperature.*" – Student 12
Application	"*How does the idea of emergency life-history stage apply to humans*?" – Student 25
Analysis	"*What is the relationship between physical characteristics, behavior and physiology?*" – Student 2
Synthesis	"*What effects would you predict if energy allocation to immune function was increased in an adult during a reproductive event?*" – Student 7
Evaluation	"*Is it really ethical to use animals, especially those of higher intelligence, in studies on the effects of psychological stress*?" – Student 25

performance was also determined by matching students initial and final assessments, where g = (F – I)/(Total – I) where (F) represents the student final assessment score, (I) represents student initial assessment score and (Total) is the total possible score on the assessment (Kohlmyer et al. 2009). The reflection rubric was converted into a numerical scale for analysis where incomplete reflections were scored as 0 to advanced reflections that were scored as 5. Chi Square analysis was used to examine relationships between student reflection rubric scores for each topic, which is used to investigate if distributions of multinomial probabilities differ (McClave and Sincich 2006). Lastly, students' reflections and inquiry sections were matched for analysis. (For detailed methods, see Appendix H).

Results

Initial and Final Assessment

The majority of students failed to respond on the initial assessment with remaining responses closely distributed (Table 4). Concepts with the highest non-response rates included.

Overall, concepts that student responses were most advanced for were acclimation and symmorphosis, isometric, and allostasis while genotype and phenotype had no non-responses.

Table 4. Percent distribution of student responses for all biological concepts for the initial and final assessments. Initial and Final Assessment N = 552.

	Non-Response	Naïve	Novice	Intermediate	Advanced
Initial Assessment	36.1	15.4	19.0	15.0	14.5
Final Assessment	4.2	3.6	13.6	19.2	59.4

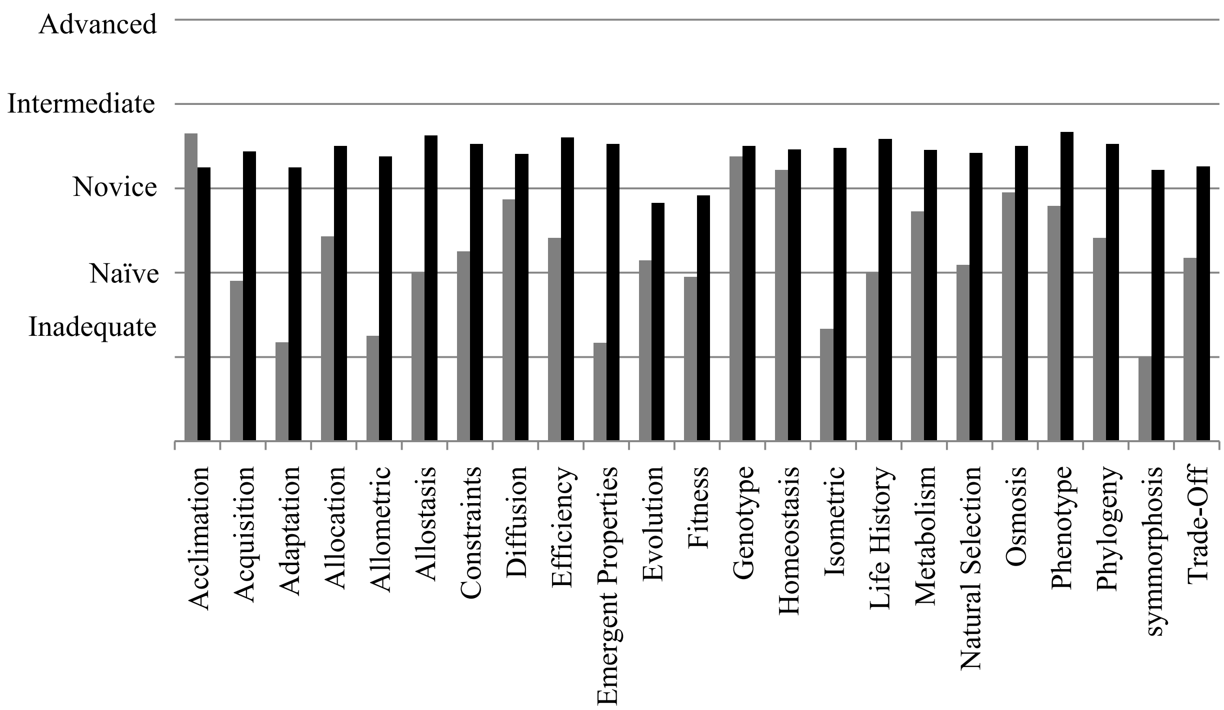

Figure 2. Comparison of student knowledge of biological concepts on initial and final assessment. The gray bars indicate average student rubric scores on the initial assessment and the black bars indicate average student rubric scores on the final assessment. Initial Assessment N = 353; Final Assessment N = 529.

Overall, concepts that student responses were most advanced for were acclimation and homeostasis and students were most naïve about adaptation, emergent properties, and symmorphosis (Figure 2). There was a substantial reduction in non-responses on the final assessment with the majority of responses determined to be advanced (Table 4). Student responses were most advanced for allostasis, constraints, life history, and phylogeny (Figure 2).

Even though students overall were knowledgeable about constraints, the concept had the second highest non-response rate. Overall student knowledge increased substantially from the initial to final assessment for all concepts except acclimation. The largest increases were found for adaptation, emergent properties, isometric, and symmorphosis. Average gain from the initial to final assessment was 0.69±0.194 illustrating a significant increase in student knowledge of concepts ($t[44] = 7.4210$, $p < 0.0001$).

Portfolio-of-Understanding

The majority of student reflections were naïve and novice (Figure 3). Thirty-nine reflections were not included in analysis, as they did not fit into a topic category (i.e., first reflections with students discussing technological difficulties and expectations and the last

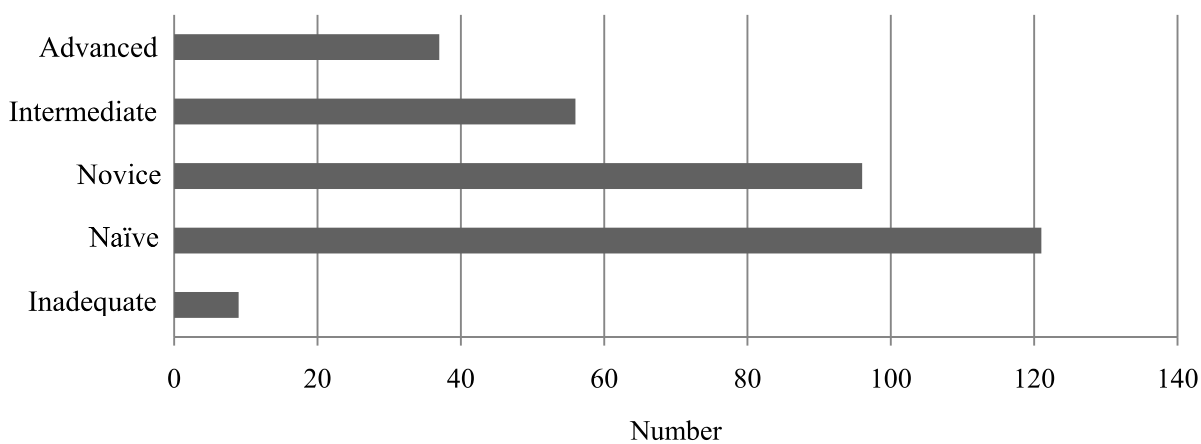

Figure 3. Distribution of student reflections based on quality. N = 319.

reflections where students summarized their course experience). (For examples of student reflections not included in analysis, see Appendix I). Students reflected substantially more often on energy acquisition while reflecting least on energy allocation and energy allocation to growth (Table 5). Not all students reflected on each topic as seen with less than half of students reflecting on energy allocation. There also was no significant difference in reflective quality

Table 5. Student reflection distribution by topic. Where (N) is the total number of reflections written on each topic, mean is the average reflection score based on the rubric ± the standard error, and the percentage of students who reflected on each topic.

Reflection Topic	N	Mean	±SE	Percent of class reflecting
Energy Acquisition	77	2.9481	0.1182	96
Energy Allocation	13	3.3077	0.2861	41
Energy Allocation to Growth	19	2.7368	0.1289	59
Energy Allocation to Reproduction	32	3.1563	0.1911	78
Energy Allocation to Self Maintenance	27	2.6667	0.1688	74
Evolution	46	3.0217	0.1878	71
Homeostasis and Allostasis	23	3.0435	0.2308	70
Life History	45	3.1556	0.1680	81
Metabolism and Scaling	37	2.7568	0.1707	93

when analyzing averages of student reflection by topic (χ^2[32, N=319] =40.999 p = 0.1323). On average, each student posed over 18 inquiry questions for a total of 507 with an almost equal distribution of questions at a higher (42%) and lower order (58%) of cognition (Table 6). There was no significant relationship between average student reflection and inquiry components (t[26] = 0.3679, p = 0.3580).

Table 6. Percentage of student inquiry in each category of Bloom's Taxonomy.

Lower Categories of Thinking		Higher Categories of Thinking			
Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
21	37	3	27	3	9

Discussion

Initial and Final Assessment

Students may not have responded on the initial assessment for a variety of reasons (Jakwerth et al. 1999). We speculate the extremely high non-response rate could be a consequence of insufficient time or a lack of knowledge. The latter would suggest the level of student knowledge of concepts on the initial assessment might in fact be artificially high. Student initial knowledge was not impacted by non-responses since they were not included in analysis. Even when students did have time to respond to a particular concept in many cases their knowledge was naïve. It is reasonable to presume that the low response rate may be a consequence of students never having been introduced to concepts before. However, even concepts introduced early and continuously through students' undergraduate courses such as evolution (Mader 2007) did not mean student responses were necessarily at an advanced level as indicated by concepts such as adaptation, fitness, phenotype, and natural selection. It is not surprising that knowledge was determined to be novice for concepts such as natural selection and evolution on the initial assessment as Nehm and Reilly (2007) found biology majors adhering to misconceptions as a course begins. Student performance on the initial assessment is troublesome as all but two of the students in the study were seniors graduating after that semester.

Student knowledge of concepts was initially weak but increased for all concepts with the exception of acclimation. The reduction in knowledge of acclimation could be due to students' early simplified view shifting as the complexity of acclimation is introduced showcasing the progression of knowledge from novice to expert (Donovan et al. 2000).It appears that overall poor performance on the initial assessment for specific topics did not affect students' ability to advance on the final. For example, student knowledge of allostasis was initially naïve but increased to be equivalent to concepts that were initially intermediate to advanced, such as homeostasis. It should be noted, that even when students had the ability to utilize resources and ample time to complete the final assessment, concepts such as constraints and efficiency still elicited non-responses. This could suggest these concepts may require additional instruction. Overall, there was a drastic reduction in non-responses on the final assessment. This is not surprising since the final assessment was graded as their final for the course unlike the initial, which was a completion activity. The difference between assessments is a limitation of this study because it could suggest that if given ample time on the initial assessment there would have been fewer non-responses and a clearer picture of student knowledge.

Portfolio-of-Understanding

There was no significant difference in student reflections between topics. A weakness of this study is that it was not possible to determine reflective quality for all students, for each topic, as not all students reflected on each topic. This discrepancy may suggest students selectively pick topics they believe would garner a better grade and avoid topics they struggled with, which may imply an artificially high level of understanding. Ultimately, such an approach would not support a deeper understanding of biological concepts. Thirty-nine reflections were not included with a substantial portion being students' first reflections which Orem (1997) suggests could be due to students being unfamiliar with reflective writing and that students benefit more when given guidance and support. A shortfall of this study is that instructor feedback on reflections was not examined. The reflection scores were averaged for each student therefore it is unclear how students' understanding may develop or regress between reflections.

Students demonstrating quality critical thinking skills are well informed, propose hypotheses, provide explanations, seek and provide evidence, and are reflective (Ennis 1996). Additional attributes include formulating questions, mindedness (i.e. narrow-minded, open-minded), and ability recognizing reliability and validity issues (Bailin 2002). Reflections have been described as vital to the process of understanding (Goodell 2000) and reflecting through writing gives students an opportunity develop ideas and make connections (Killion 1999) turning learning into a synergistic process (King and LaRocco 2006). When analyzing students' reflections attributes that indicated critical thinking included students posing questions, tying content from class to personal experience, and consultation with outside resources to supplement understanding. Together, these suggest that students were becoming self-directed, a common aim of portfolio-based assessment (Kicken et al. 2009; Paulson et al. 1991) and an essential element of thinking critically (Ennis 1996).

Few studies have examined students' ability to pose questions. However, when applying Bloom's Taxonomy to traditional exams the majority of questions are knowledge based with a fraction of questions at higher levels (Lord and Baviskar 2007). Students' ability to pose higher level of questions is of particular importance since this skill forms the basis of good science (Marbach-Ad and Sokolove 2000). When examining questions posed by students in an undergraduate physics course Harper et al. (2003) found that conceptual student achievement could be predicted based upon student questions in that asking high-level questions relates to a better conceptual understanding. Teaching students the skill of generating questions has also been linked to increased comprehension (Rosenshine et al. 1996). We found an almost equal distribution in students' inquiry between lower and higher-level questions implying students are able to critically think about content and perhaps have a better understanding of concepts.

The two components of the Portfolio-of-Understanding analyzed in this study show that not only do students understand course content but also critically think about content. The gain in student knowledge of biological concepts increased significantly over the duration of the course, which provides support for implementation of portfolio-based assessment. In addition, other studies in the medical profession have found portfolios effective at assessing learning (Mathers et al. 1999) and for personal and professional development (Gordon 2003).

As students are generally assessed using traditional exams there may be a learning curve for students to develop skills and abilities to raise themselves to the level required by this type of assessment. Weaknesses of portfolio-based assessment may exist due to the innate relationship with strong communication skills. This study analyzed only written aspects of student performance; it is possible students with poor written communication skills were at a disadvantage. Potentially even if students cannot articulate their understanding in a reflection or inquiry it does not necessarily mean they have a weak understanding of content. Strong communication skills alone may put certain students at a disadvantage with this type of assessment. Other assessments may also be disadvantageous to certain students as well, as seen with students who suffer from test anxiety with traditional exams.

Conclusion

Portfolio-based assessment has been referred to as the intersection between instruction and assessment (Paulson et al. 1991). Although educators teach for understanding, few undergraduates actually retain information from their science courses (Lord and Baviskar 2007) as highlighted by the low initial knowledge of concepts found in this study. This portfolio-based assessment course illustrates student knowledge of biological concepts increased significantly, students critically thought about content, and were able to demonstrate their understanding through written reflections and inquiries. Portfolio-based assessment can be an appropriate means of assessment in courses that strive to promote a deeper understanding of biological concepts.

We do not claim that portfolio-based assessment is the best, or only, way to promote student understanding and critical thinking in an upper-level science course. As with any type of assessment there are concerns to be considered before implementation. Instructors must determine what their learning goals are for students, why they are assessing students, and then consider the best assessment method in order to help drive student learning (Crowe et al. 2008). This study is one of the first examining portfolio-based assessment in an undergraduate course let alone in an upper-level science course. Implementing portfolio-based assessment may be a method to improve student understanding of biological concepts and this study provides an essential step in evaluating a non-traditional assessment method.

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PAPER 2. EXAMINING INTEGRATIVE THINKING THROUGH THE TRANSFORMATION OF STUDENTS' WRITTEN REFLECTIONS INTO CONCEPT WEBS

Abstract

A shift is currently taking place in which explicit connections between content are being emphasized. Biology is not an isolated discipline yet undergraduate courses frequently focus on discrete knowledge. Students often engage in rote learning, struggle with transforming, and applying content. Integrative thinking occurs when students recognize connections to content. Written reflections provide students with the opportunity to demonstrate this thinking. We transformed student written reflections into concept webs in order to gain insight into how students connect biological concepts. We were interested in determining if characteristics of integrative thinking develop through reflections, describing the differences in students' integrative thinking. Results indicate a significant relationship between concepts and integrated relationships. Integrative thinking varied but declined overall. Concept webs allow for examination of student integrative thinking through the transformation of reflections. Reflections can transform learning by facilitating and allowing for the evaluation of integrative thinking.

Introduction

Following years of education focused on isolated discrete knowledge, a shift is occurring towards an explicit emphasis on connections (Humphreys 2005) in instruction and assessment. Science as a discipline is not isolated, and should not be isolated, in learning environments. Learning outcomes should include an emphasis on integrative thinking with students being able to recognize connections between biological concepts. Often, though, content is centered on disconnected pieces of knowledge where courses are fragmented from each other (Huber et al.

2005) and undergraduate students frequently engage in rote learning (Tomanek and Montplaisir 2004). Briscoe and LaMaster (1991) contend that many undergraduate students do not remember concepts beyond their final exam, do not connect them to personal experiences, and rarely consider concepts meaningful to their own lives. Additionally, students struggle with transforming knowledge across subject areas (Perkins 1993). These findings should not be surprising since instruction and assessment often focus on specific detailed information (Lord 1998) which can potentially give students the wrong impression because of the emphasis placed on grades (Taras 2002).

Integrative thinking is the ability to recognize relationships, make connections, and synthesize content which can foster meaningful learning because students are not only knowledgeable about facts but also can use them (Michael 2004), draw connections (Mayer 2002), and interpret, incorporate, and relate new knowledge with prior knowledge (Herman et al. 1992; Novak and Gowin 1984). Integrative thinking potentially makes learning science difficult, as biology requires students to integrate concepts across levels of organization in order to synthesis and analyze content (AAAS 2009). A study examining undergraduate physiology student problem-based writing with peer review, found that students have difficulty relating concepts and problems recognizing organizational levels (Pelaez 2002). However, it is essential for students to learn how to integrate knowledge because learning facts that are isolated from concepts and contexts are ineffective in helping students understand biology. Specifically, knowledge needs to be integrated into students' previous frameworks (Mayer 2002) as meaningful learning starts with the construction of mental models or representations of knowledge (Michael 2004).

In order to facilitate students' drawing connections between content, there is a need not only to develop assessments that foster integration (Huber et al. 2005) and to determine prevalence of student difficulties in determining relationships (Pelaez 2002) but also allow for integrative thinking to be effectively evaluated. Portfolios provide a means to support integrative and connected learning specifically through the use of reflections (Huber et al. 2005). Reflections can provide an opportunity for students to connect content (Killion 1999) as analytical writing can be a means for students to transform ideas into structured and coherent knowledge (Rivard and Straw 2000). Quality reflections have been found to be comprised of multiple characteristics including drawing connections between content, previous learning, and experiences (Ziegler and Montplaisir, in press; Killion 1999). Previous research analyzing student reflections commonly examine the quality of reflective thinking or writing (Ziegler and Montplaisir, in press; Zapata-Rivera and Greer 2003; Richardson and Maltby 1995). This study was designed to develop a method in which student integrative thinking could be evaluated through the transformation of student written reflections. Developing a method that allows for insight into how students draw relationships between content can help in understanding how students potentially integrate knowledge and may also provide insight into how integrative thinking can be fostered in students.

Theoretical Framework

The primary component of assimilation learning theory is meaningful learning (Ausubel 1968) which is the foundation of constructivism (Novak 1990b). Meaningful learning, as described by Ausubel (1968), is a process where ideas are expressed in a non-random and non-verbatim way that is relevant to students' current knowledge structure. This type of learning differs from rote learning in which individuals primarily memorize new knowledge verbatim and may not be integrated into individual's current knowledge structure (Novak and Gowin 1984). New information that aligns with a previously developed understanding allows for connections and relationships to be reinforced, broken down, and restructured (Lee 1997). Ausubel (1968) explains that acquiring knowledge and understanding involves an individual relating and reconciling new content within their existing knowledge framework. Assimilation learning theory explains how that knowledge is structured and organized. Assimilation learning theory and constructivism are linked as constructivism broadens and utilizes ideas established by Ausubel to classroom settings (Bretz 2001).

Knowledge is not discovered but is actively constructed with the individual doing the learning (Bodner 2007). Constructivist theory focuses on how individuals make sense of their experiences during the learning process and how people come to know (Bodner 2007). In constructivism, individuals are actively engaged in the learning process because the learner must pay attention to relevant content, organize it coherently, and integrate it with their existing knowledge (Mayer 1999).

Methods

Research Context

This study took place during the Spring 2009 semester of Physiological Ecology at a large land-grant research university in the Midwest. The course was a three-credit, upper-level elective biology course, that met three times weekly and covered physiological mechanisms underlying life-history trade-offs and constraints in an ecological and evolutionary context. The course emphasized building upon previous coursework to understand complex concepts and connections across biology (Appendix J). One of the main learning objectives of the course was for students to recognize and understand relationships between concepts (Appendix B). While the only prerequisite for this course was a semester of introductory “organismal” biology lecture and laboratory, the majority of students were graduating seniors who had already completed over 24 semester credits of biology.

Instruction was primarily teacher-centered and lecture-based but was intermixed with student discussions. Students were evaluated using portfolio-based assessment supplemented with reading quizzes. Student portfolios accounted for over 80% of student’s final grade. This study coincided with the first semester portfolio-based assessment as was implemented by the instructor. Student portfolios were comprised of four sections: inquiry, lecture notes, literature and written reflections. This study only examined student written reflections. Students were instructed to reflect on course content, link material to previous experiences and interests, and provide material from outside sources such as primary literature and other coursework. Students had the freedom to reflect on any topic related to class and reflections were not written in response to any prompt or question. Students could write portfolios at anytime, independent of when lectures occurred, but at a minimum, weekly contribution to each section of the portfolios was required. Therefore, each student should have submitted at least 14 one-page reflections to meet the minimum requirements for the course. The instructor assessed each student’s work four times over the semester and could provide feedback, which may have included guidance or additional questions for response. The syllabus encouraged students to revisit and expand previous reflections as their understanding developed. One aspect in which student portfolios were graded was based upon quality of evidence students provided to demonstrate a thorough understanding of content and ability to make connections among concepts across the semester. The evidence evaluated focused on creative thinking and students’ ability to synthesize and integrate material from the course (Appendix B).

Coursework for 41 undergraduate students was analyzed. Seniors accounted for 83% of the students and 68% were zoology majors. There was an equal distribution of males and females (M = 21; F = 20). IRB approval was #SM10164 (Appendix D).

Transformation of Reflections into Concept Webs

At the beginning of the course, students completed an in-class activity in which they were required to define 23 concepts, deemed to be essential concepts in the course by the instructor. This activity provided researchers guidance in determining concepts that were likely to emerge while transforming student reflections. The concepts included in concept webs emerged based on their utilization in student reflections. For the purposes of analysis, two researchers, independent of the course, retroactively transformed student reflections into what we termed concept webs. During this process, reflections from five students were transformed totaling 65 concept webs. Any disagreements were discussed until each was resolved and then one researcher continued to finish transforming student reflections (n = 408). The methods utilized in the transformation process were adapted from those outlined by Novak (1990a). This study developed a mix-mode method that combined the advantages of different visualization tools (Eppler 2006). Specifically, our methods differ from Novak (1990a; 1990b) who transformed interview data into concept maps in that concept maps have a hierarchical top-down format and reading direction. Rather, we followed the contention outlined by Herman et al. (1992) who stated that learning is not linear and therefore does not necessarily proceed in distinct hierarchies. Based upon this view we transformed reflections into concept webs that were not hierarchical and had no designated reading direction but incorporated relationships between concepts. Concept maps provide an opportunity to visualize the integration of information and the structure of knowledge (Akinsanya and Williams 2004). We also did not examine correctness of concepts and relationships, which differs from other studies utilizing concept maps (Novak and Gowin 1984). Identifying validity of concepts and relationships can be unsupportive in promoting future learning and in gaining a clear understanding of student knowledge, because invalid relationships can potentially provide support for other relationships that are valid (Kinchin 2001). Therefore, in order to gain a clear picture of student thinking we included as many components of student thinking as possible. Concept webs were not coded based on completeness nor compared to expert concept webs. Examples below from students' reflections show how student written reflections were transformed into concept webs (Figures 4 through 6) (For narrative explaining process of transforming concept web in Figure 4, see Appendix K).

> *"... I know that **adaptation** is an **evolutionary** process of change, but I didn't know that it was in the **genotype** over a long period of time like generations. Acclimation was a word that I sort of knew, but I didn't know that it was an animals response over a shorter period of time, like how we in North Dakota are **acclimated** to the cold, but in the summer we are **acclimated** to the hot **environment**. I thought that a **phenotype** was just an expressed observable trait, but its more than that. Its **morphology**, **physiology**, and **behavior**, and they all reflect each other. **Genes** and the **environment** play an important role on **phenotype**...This reading was a good example of how **behavior** and **morphology** reflect each other in a **phenotype**. The behavior of how strong bite force is based on the morphology factor of how wide its head is."* - Student 130

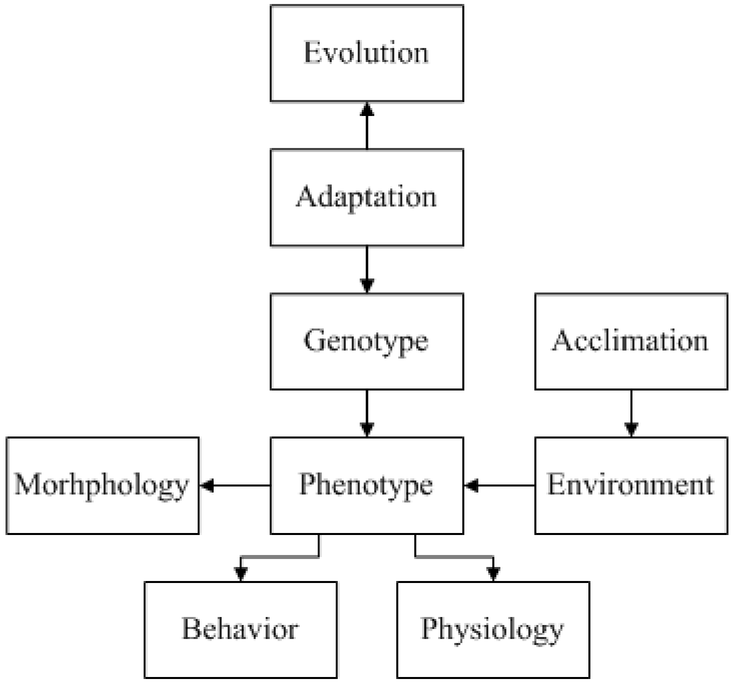

Figure 4. Example of student 130 reflection transformed into concept web.

> *"This week, in class we discussed the **physiology** and **hormones** that are involved with **reproduction**. This was an interesting topic because it is important to realize that **hormones** play a major role in not just **reproduction**, but in other major body systems as well. Hormones are chemical signals that are release by a cell carried in circulation, and regulates another cell. There are 3 types, which are autocrine, paracine, and endocrine. There are also different types of **hormones**, such as developmental hormones and regulatory hormones. Each, playing a vital role in the body, whether it be **reproduction**, **homeostasis**, **growth**, or **phenotype**. There are two molecular actions associated with hormones, and they are protein peptide and steroid hormones..."* – Student 116

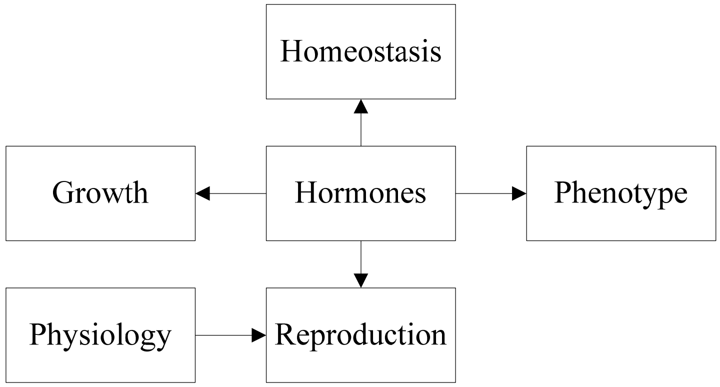

Figure 5. Example of student 116 reflection transformed into concept web.

> *"...**Allometry/isometry** is the comparison of log of data. It is **isometric** if it has a log to log slope of 1. It is **Allometric** if it has a log to log slope of less than 1 (negative **allometry**) or greater than 1 (possitive [sic] **Allometry**). **Scaling** Larger animals have greater absolute **metabolic** need than smaller animals. But as an animal increases in body mass there **metabolic** rate decrease, Per unit weight smaller animals have a larger **metabolic** need. 1000 kg of mice need more than 1000kg of elephants. The **scaling** of **BMR** to mass helps us understand many different things about an animal like home range size. If an animal needs x amount of cal/kg then we can tell how big of a territory it needs if we know how good the territory in cal/acre. **Energy** as a unit of **fitness**. Simple Models A habitat contains a set amount of energy lets say 9, if a certain number of animals lets say 3 are all living in this habitat and competing for a portion of this set amount of resources, All animals require at least 3 units to survive and I additional unit per offspring. All three can live in this habitat their fitness would be 0 because none would have the **energy** to **reproduce**. So an individual needs to collect more of the available energy from the habitat to reproduce the more it collects the more offspring it can have. Lets say for some reason animal a is better at collecting energy and can collect 5 of the 9 available units Then it can produce 2 offspring raises its fitness to 2 but leaves only 4 to be shared by animal c and d. This leaves either both of them dead, 1 dead and the other living, or 1 dead and the other with 1 offspring. With this simplistic model it is easy to see how **energy** can greatly effect **fitness**, on both levels of **fitness**, the **reproduction** rate and the survival rate of an organism."* – Student 140.

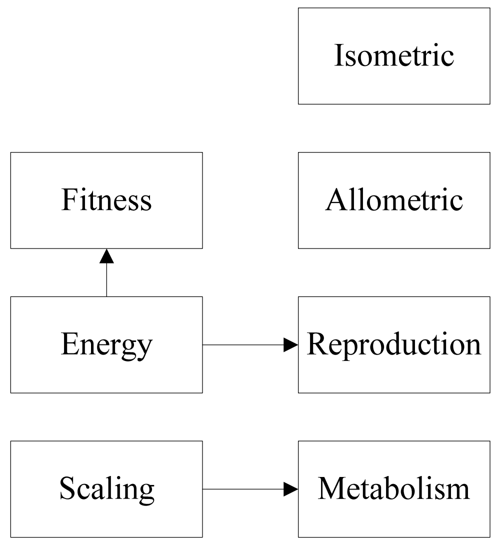

Figure 6. Example of student 140 reflection transformed into concept web.

Analysis

Concepts were included in a web not only if a student used the term explicitly but also if the student implicitly referred to it, for example, using the definition in their reflection without the term. In addition, if students used synonyms for concepts, such as energy consumption instead of energy acquisition it was included in concept webs. Relationships could link two concepts together or link a relationship and concept. Relationships and concepts from all concept webs were included for analysis. Within a single reflection, students could have referred to relationships between two concepts more than once. For the purposes of our analysis, relationships were included based on whether it was present in the reflection, not how many times it was described. It was not our goal to examine adequacy of relationships or be restrictive in examining student integrative thinking. Within concept webs, the presence and number of concepts, relationships and interconnections were examined. Following this evaluation, the concept web in Figure 7 contains 13 concepts and 12 relationships. When examining the relationships more closely, 10 relationships represented by solid lines indicate relationships

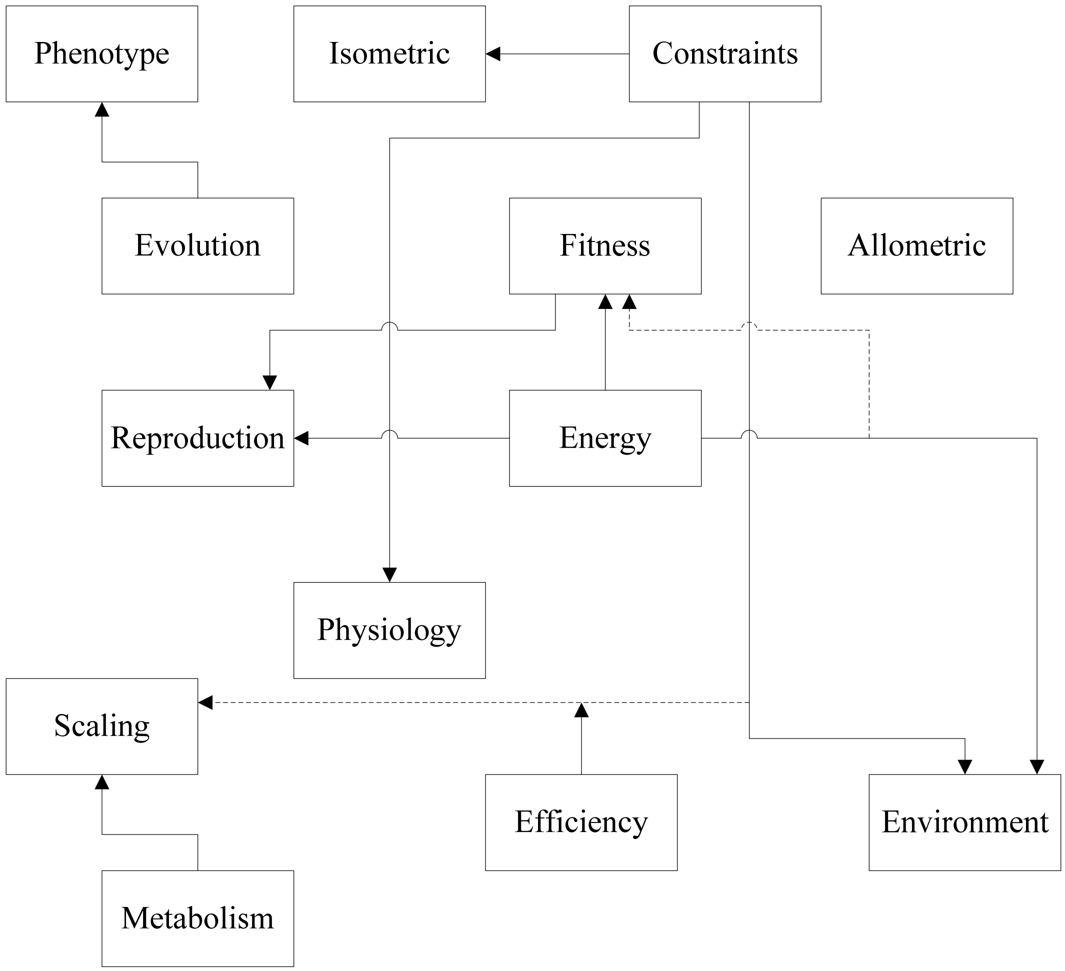

Figure 7. Concept web example.

between two concepts. The other two relationships represented by dashed lines indicate a student recognizing that the interaction between two concepts can be linked to another concept. For example, in Figure 7 this student recognized a relationship between energy and environment but also realized that the interaction between these concepts is connected to fitness. Interconnections were calculated similarly to Martin et al. (2000) by determining the number of relationships per concept present. Therefore, the interconnection ratio for Figure 7 is 0.92. If interconnections could not be calculated, they were excluded from analysis. We also analyzed isolated concepts in concept webs to determine which concepts if any, students may have difficulty recognizing relationships with. There are no isolated concepts in Figure 7.

Results

A total of 473 reflections were transformed into concept webs, 12 of the reflections did not contain concepts or relationships, and therefore on average each student contributed 11 reflections. Thirty-six concepts emerged from reflections. On average concepts webs contained more concepts (*M* = 5.1165, *SD* = 3.4131) than relationships (*M* = 3.3750, *SD* = 3.6394) and the mean interconnections was 0.6083±0.3155. There is a significant relationship between the number of concepts and relationships ($F_{1, 471} = 4582.47$, $p < 0.0001$, $R^2 = 0.8352$) and the distribution of which was not equal. The most common concepts in webs included energy (10.96%), environment (7.28%), and reproduction (7.03%). Emergent properties, osmosis, and phylogeny were the most uncommon concepts and accounted for less than 1% of concepts present. The mean number of relationships connected to a concept was 1.340±1.018 with allocation (*M* = 2.1373, *SD* = 1.3714), phenotype (*M* = 2.0492, *SD* = 1.5103), and genotype (*M* = 1.8235, *SD* = 1.1438) garnering on average the most relationships. Osmosis did not garner any relationships (Figure 8) and relationships to emergent properties (*M* = 0.250, *SD* = 0.500), isometric (*M* = 0.5, *SD* = 0.5189), and allometric (*M* = 0.6897, *SD* = 0.8495) on average garnered the fewest relationships. There was an overall drop in concepts, relationships, and interconnections over duration of the course however substantial variability exists (Figure 9 and 10). Mean concepts for the four weeks varied significantly ($F_{3, 104} = 11.2360$, $p < 0.0001$). There also was a significant difference between relationships in concept webs from different weeks ($F_{3, 104} = 7.0693$, $p = 0.0002$) and interconnections ($F_{3, 99} = 2.6927$, $p = 0.0502$). When

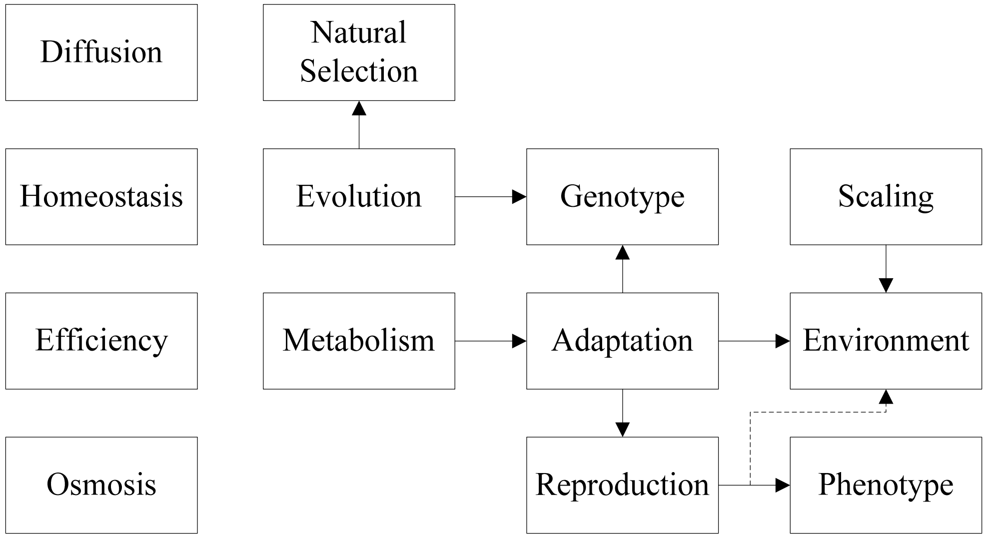

Figure 8. Example of concept web showing isolated concepts.

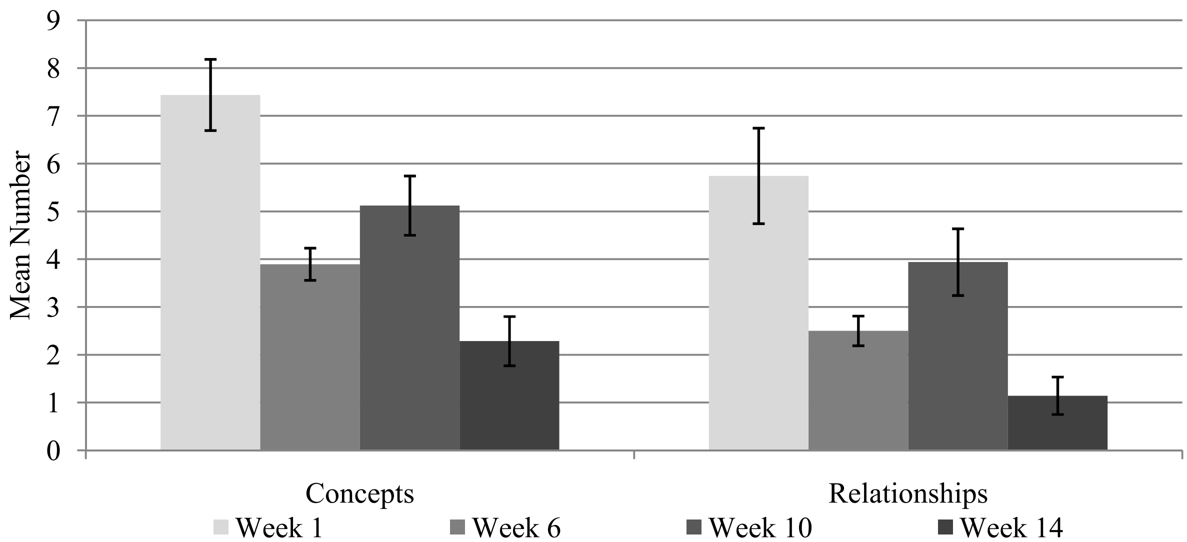

Figure 9. The distribution of mean concepts and relationships from four weeks during the course. Bars represent standard error.

examining concept webs from the first four weeks compared to those after week ten, again there was a significant decline in concepts ($F_{1,251} = 13.5416$, $p = 0.0003$), relationships, ($F_{1,251} = 8.7205$, $p = 0.0034$) but not for interconnections ($F_{1,240} = 3.8335$, $p = 0.0514$). When matching student concepts webs from the first four weeks to those after week ten 24.4% had an increase in

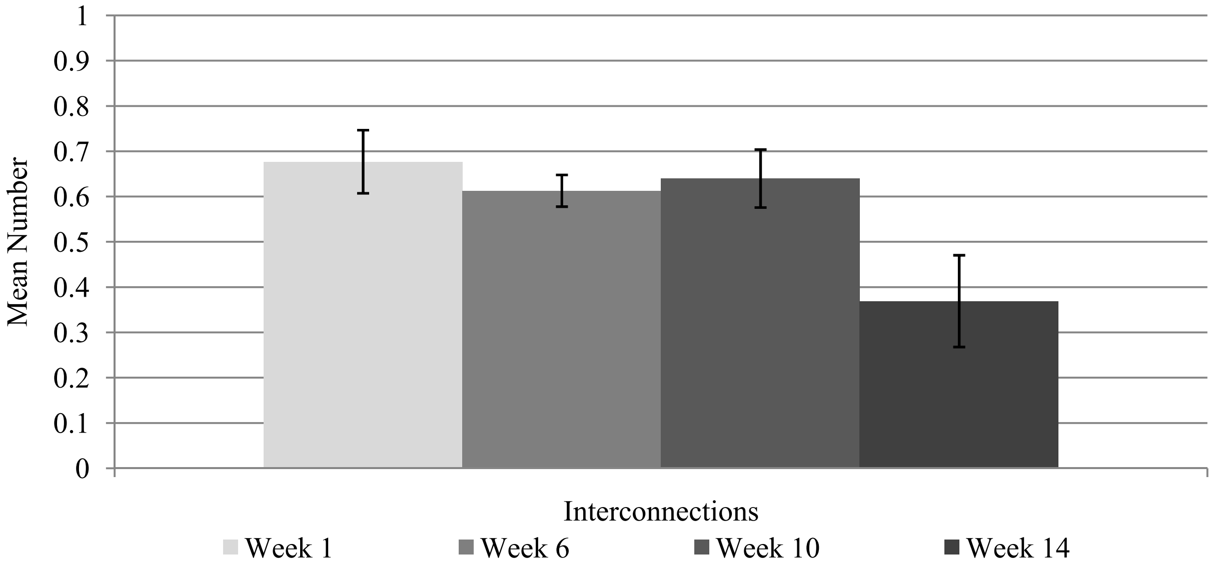

Figure 10. The distribution of mean interconnections from four weeks during the course. Bars represent standard error.

relationships, 14.6% had an increase in concepts, and 19.5% showed an increase in interconnections.

Discussion

Concepts, relationships, and interconnections, although variable, decreased significantly from the beginning to the end of the course. These results are not consistent with those from a study conducted by Martin et al. (2000) who examined the restructuring of undergraduate students' knowledge in biology finding that concepts and relationships increased while interconnections decreased. An explanation for why concepts, relationships and interconnections were significantly higher at the beginning of the semester may be due to the course being content heavy at the beginning (Martin et al. 2000) while focusing on specific topics as the course progressed.

In addition, students struggling to integrate concepts into their existing knowledge frameworks may explain the decline. It is presumable that certain concepts are easier or more difficult for students to integrate than others are which may explain why certain concepts are used more frequently and garner more relationships than others. Student concept webs may in fact be well integrated with rates of interconnections but that does not necessarily mean students do not still struggle with integrating certain concepts. In the case of the students' reflections transformed in Figure 4 and 6, there are still multiple concepts that are isolated. This could provide insight into which biological concepts students struggle with integrating to other concepts and potentially inform instruction. It is possible that students' key in on specific concepts and relationships they deem pertinent which could also provide insight into student thinking. If student concept webs contained a high number of concepts with relatively few relationships, which would result in a low interconnection ratio, this may suggest students are employing rote-learning approaches (Martin et al. 2000). In our study, the presence of concepts and relationships are related suggesting that although the presence of concepts and relationships decline overall, the concepts present are being integrated. This is represented through interconnections in student reflections being less variable than concepts and relationships.

There can be great variability in student mental models ranging from models that tend to exhibit models that are complete, coherent, consistent, and are richly interconnected while other models tend to be incomplete, disjointed, inconsistent, and poorly interconnected models (Michael 2004). It remains unclear how a student develops integrative thinking skills. Shuell (1990) explains that a continuum exists in which students' progress through learning phases. In the initial phase, students have a vast array of facts and bits of knowledge that are isolated and engage in rote learning. Gradually students begin to recognize connections or relationships between knowledge that was previously isolated. Then during the last or terminal phase, the knowledge becomes complexly integrated. Building upon Lee (1997), a potential for developing integrative thinking in students may be to share models with students in order for them to gain confidence in their ability to organize and shape their knowledge.

In this study, we do not know if certain students had a better initial understanding of concepts, which may predispose them for writing reflections that when transformed, had more highly integrated concept webs compared to other students. This distinction may be of importance because in order to learn meaningfully students need to possess background knowledge (Novak and Cañas 2006). It does not appear though that students are incapable of integrating knowledge but some may have a narrower foundation of knowledge on which to integrate.

Conclusion

In order to learn in a meaningful way, students need to be able to connect new content with prior knowledge. Associating content and integrating knowledge are essential when promoting a deep understanding of biological content and student reflections provide a means for students to integrate knowledge. To gain insight into integrative thinking, in this study we developed a method to transform student written reflections into concept webs. To do so, a mix-mode method was developed that combined the advantages of different visualization tools (Eppler 2006). The type of visualization used in this study combined multiple visual formats, which we found beneficial and effective for determining student integrative thinking as well as patterns and characteristics that emerged in concept webs. All visualizations have positives and negatives, the concept webs we developed incorporated a variety of the positives while minimizing negatives. For instance, concept maps allow for a systematic overview, emphasis on relationships between concepts, and ability to assess quality (Eppler 2006) these features were incorporated into our concept webs. However, our concept webs were not organized hierarchically, were not compared to expert representations, and were not formed to answer a specific question, which are characteristics of concept maps (Novak and Cañas 2006). The concept webs developed in the study may provide a more authentic visualization of student knowledge because student reflections were not written to answer a specific question or in order to demonstrate a potential expert understanding. The concept webs transformed from student reflection represent actual student thinking without the students being graded for whether or not a correct answer or expert level of thinking is being achieved.

By researching how students structure their knowledge and draw relationships between content, we can build knowledge about how students potentially structure and integrate knowledge and how to foster the development of this skill. The model describes the nature of student knowledge of biological concepts and may be informative in helping to promote the development of integrative thinking in students. This approach allows researchers and instructors to characterize student integrative thinking and reveal challenges students may have. This method of transforming reflections into concept webs therefore may have implications for practitioners as well in helping to gain insight into whether students are meeting learning goals.

In order to understand student integrative thinking we need to understand how their knowledge is structured (Chi 2006). This study represents a step forward in developing methods that can be used to assess and to enhance students' integrative thinking in. Examining assessment methods is extremely valuable because it can help in transforming biology undergraduate education (AAAS 2009). Connections are an integral part of learning and developing integrative thinking should be an important goal for our students. Assessment approaches such as portfolios and reflections may be a means to facilitate students becoming integrative thinkers. Ultimately, this study provides a means to gain insight into how student think and develop an understanding about complex biological phenomenon through the use of transforming student written reflections into concept webs.

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CONCLUDING REMARKS

Summary of Findings

The process of learning is innately connected to assessment. We must think about assessment before instruction and learning but after learning outcomes have been identified because student learning cannot be effectively assessed unless what students are suppose to learn has already been established (Wiggins and McTighe 2005). The method of assessment, implementation of that assessment, and the learning environment need to be taken into account, all of which were investigated in this study. In addition, when evaluating assessments key elements need to be considered (Pelligrino et al. 2001; Shavelson and Ruiz-Primo 2003). There must be a clear definition of what is being measured with assessment, the assessment itself needs to provide a means to elicit and collect behavior, to allow behavior to be observed in relation to the assessment, and be able to make valid interpretations about behavior on the assessment to the construct that is being measured (Shavelson and Ruiz-Primo 2003). The objective of this doctoral study was to examine portfolio-based assessment implemented in an upper-level biology course. In this study, I measured the quality of student reflections, cognitive level of questions, learning gains of biological concepts, and evidence of integrative thinking in an undergraduate biological sciences course in which portfolio-based assessment was implemented. This study was guided by constructivism, which dictates that learning is achieved when the learner is actively engaged and involved in the learning process. Bodner (2007) explains that constructivism deals with “individuals making sense of their experiences.” In many ways, constructivism has become the pinnacle of science and biology education research.

Portfolio-based assessment emphasizes constructivism in that it provides opportunities for students’ ideas and experiences to interact with biology content and is a mechanism to gain insight into students' understanding. Portfolios can reveal student's meaning (Engel 1994) by having students responsible for providing evidence that learning goals have been met (Biggs and Tang 1997). In portfolio-based assessment, emphasis is placed on what evidence the student constructs. Specifically, reflections in portfolio-based assessment provide opportunities for students to create their own meaning about content while being active in the learning process and inquiry gives students opportunities to engage in the process of science and can be an essential resource to gain insight into student learning.

Through this study, it was found that students' knowledge of biology concepts increased, students have the capability to write quality reflections, and high cognitive level questions that highlight attributes that coincide with critical thinking in a course that implemented portfolio-based assessment. When examining student reflections, a substantial range in quality was found but students were able to connect course content to personal experiences and prior knowledge, consulted outside sources such as primary literature, and apply course content to novel situations.

As for students' inquiry, although low-level cognitive questions composed the majority of student questions in most cases, the amount of high-level cognitive questions was still substantial. The findings from this study show that assessment can be a significant factor in promoting students to ask high-level cognitive questions. It is presumable that in order to foster students' ability to ask high-cognitive level questions students need to be given the opportunity, which this form of portfolio-based assessment provided. It is not simply asking questions that is important in science though but the types of questions that are asked.

This study developed a research tool that allowed students' written reflections to be transformed into concept webs. The concept webs developed this in this study showed a wide range of students' ability to integrate biological concepts. The ability for students to connect or integrate knowledge is essential to learning that may explain the advent of holism and systems thinking approaches to science. Cross (1999) explains this role profoundly and simply by stating that, “learning is about making connections.” In order to learn in a meaningful way, students need to connect or integrate new content with prior knowledge.

Implications

A thorough understanding of portfolio-based assessment and its specific components can help to support practices that utilize this assessment method. Portfolio-based assessment may provide students with learning opportunities that support reflective thinking, ability to pose questions, and integrate biological concepts. For instance, this assessment method may facilitate knowledge construction through active engagement and reflection during the learning process. Ultimately, knowledge needs to be constructed by the learner and portfolio-based assessment can help to facilitate this construction. Adhering to learning theories can be a concern for practitioners in science disciplines due to numerous aspects being beyond student experiences and difficulty in demonstration (Matthews 2002). Providing opportunities for students to be actively engaged, link content to prior knowledge, and construct rather than acquire their knowledge are vital to students learning in a meaningful manner. Portfolio-based assessment provides a means to unite assessment and how students learn.

This study also outlines a research model that provides a means to evaluate student integrative thinking through evidence of connections and relationships students draw between concepts. Portfolio-based assessment can be an informative research tool by providing a means to gain insight into student integrative thinking through written reflections. Transforming student written reflection into a concept web allows for a visualization of potential student knowledge structures, which are informative in meaningful learning. In addition, gaining insight into students' mental models of biological knowledge can be informative in guiding students through the process of thinking in an integrative manner.

The portfolios students create as part of portfolio-based assessment are unique. No two students are the same and unlike traditional assessments where all students complete the same activity, portfolio-based assessment embraces and allows for student individuality. By their nature, portfolios are individualized and therefore difficult to standardize. This leads to issues over reliability and validity, in addition other issues exist that practitioners should be aware of before implementing portfolio-based assessment.

Limitations

I have presented my interpretations of the results from this study but as with all studies, limitations exist. Direct comparisons based on week and topic cannot be made because students chose to write reflections and questions on different topics. However, student choice is a way to motivate students and is a value of portfolio-based assessment (Davies and Mahieu 2003). Due to this, though it is difficult to determine student progress over the semester for a particular topic or concept since students did not necessarily reflect on a topic or a concept initially or more than once.

It is possible that the standards defined in this study for reflection, inquiries, integrative thinking did not align with those outlined by the instructor. It is possible that the rubrics developed for this study went beyond the learning goals identified by the instructor. Therefore, students could meet the instructor's standards, as seen by student final grades, but not those outlined in this study. This may explain the differences in reflective quality found but not final grades between semesters. Nevertheless, reflection is an essential component of portfolio-based assessment and an important facet of the learning process that should be facilitated.

Another limitation of this study is that the course was not observed. It is possible that although the form of portfolio-based assessment implemented was the same and state learning outcomes identical in all the semesters examined, instructional differences could have occurred in which different components or the portfolio were emphasized or different learning outcomes articulated. In addition, the form of portfolio-based assessment did not necessary follow all the guidelines that have been established for the implementation of this type of assessment. For instance, students were not involved in the process of determine what components would be included in the portfolios or how those components would be evaluated. However, students were given the freedom within the components the instructor developed. Students had the freedom to decide what topics they would like to reflect on or inquire about. This is important to be noted because the role students have in the learning process is essential, specifically in portfolio-based assessment (Paulson and Paulson 1994). The procedures in which portfolio-based assessment was developed and implemented in this course may represent a more highly structured utilization of this method of assessment than what has previously been examined and implemented in other studies.

It is not presumed that students withheld or did not disclose information as the researcher was not a permanent fixture of the course and students were not asked to complete any additional work for this study. It is possible though students' may have altered how they would normally approach a course due to being a participant. No information about students' perception or views about being a participant were collected therefore it is unclear whether or not participating influenced the work completed for the course. My direct role with students was minimal because I only had direct contact with students when asking for permission to participant and their work gathered indirectly.

Conclusion

The conclusions that can be drawn from this study are limited in scope because the study was exploratory and descriptive in nature. Although, this study in some regards included several semesters, it represents only one course with a specific subset of students. It is presumable that different results would be found in different courses. Before implementing any method of assessment, including portfolio-based assessment, the student population, learning outcomes, and purpose need to be considered. Portfolio-based assessment is a way to promote understanding of biology, reflective thinking, posing high cognitive questions, as well as thinking integrative through reflections. This study is one of few examining portfolio-based assessment and in an upper-level biology course. The findings from this study suggest that the role of assessment is an essential component in the learning process.

The goals of this study were to examine student knowledge of biology, ability to reflect, inquire, and think in an integrative manner. Based on the findings we conclude that portfolio-based assessment as implemented in this course is not necessarily the best or only way to promote student understanding of biology but it does illustrate potential. We cannot say that students would not have been reflective, pose questions or integrative think with a different type of assessment.

Assessment is one of the most important features, if not the most important, in influencing student learning. For assessment methods to be effective, they need to be built upon how students learn. Portfolio-based assessment, a method of alternative assessment, highlights the current understanding of how students learn. This study contributes to the limited research concerning portfolio-based assessment in higher education and specifically in biological sciences. Currently, the role of portfolio-based assessment in science education remains unclear.

Assessment can significantly affect student learning and has the potential to transform learning. Additional research is needed before we will fully understand the potential possibilities and implications for portfolio-based assessment.

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APPENDIX A. SPRING 2010 COURSE SYLLABUS.

Spring 2010
Physiological Ecology 462
MWF 11:00-12:50, 230 Stevens

Dr. Wendy Reed, Wendy.Reed@ndsu.edu
Office: Stevens 311, office hours: any open time, I post a schedule of my weekly schedule on my office door, please stop by my office and sign up for an open time that works with your schedule.

Readings: We will be reading a book over the course of the semester, as well as articles from the primary literature. Any general physiology textbook will serve well if you need a reference.

Required books:

In the beat of a heart. Life, energy and the unity of nature. John Whitfield. 2006. Joseph Henry Press. *This book is available online. There is a website for the book (http://www.inthebeatofaheart.com/) with links for purchase options. You can read the entire book online for free, purchase a downloaded pdf version, or purchase a hard copy. Keep track of this website, there are useful updates and information regarding the topic of scaling in biology and it might be helpful for discussions.*

Recommended Physiology Textbooks: These are books that provide a good reference, they are not required for the course, but will provide additional background if you feel like to need more information.

Wilmer, Stone and Johnston. 2005. Environmental Physiology of Animals. 2nd edition. Blackwell Publishing.
Hill, Wise and Anderson. 2004. Animal Physiology. Any edition. Sinauer Publishing. *this is the same text used in Zoology 460.

Attendance: You are encouraged to attend class, but attendance is not mandatory. You are expected to be in class on time. If you are going to be late, do not interrupt class. Please make arrangements to get notes from a classmate.

Course Description: Study of the physiological mechanisms underlying life-history trade-offs and constraints in an ecological and evolutionary context.

Course Objectives: At the end of the course I expect students will have accomplished the following goals:

1. Become familiar with the basic terminology and concepts in physiological ecology
2. Gain an understanding of physiological adaptation and evolution by natural selection
3. Gain the ability to synthesize information from the primary literature with an emphasis on graphs

The exercises I have selected are designed to help you accomplish these goals.

Evaluations:
You will have the opportunity to earn 200 pts over the course of the semester.

Portfolio (175 pts, 88%): You will be building a portfolio of understanding over the course of the semester. The portfolio will be evaluated 4 times during the semester (40 pts first evaluation, 45 pts 2nd 3rd, and final), at approximately 4-week intervals. A rubric will be provided.

Quizzes: (5) 5 pts each = 25 pts (12%). Quizzes will cover material from the readings and lectures.

Grading Policy
I will not give you a grade; you are responsible for earning your grade by demonstrating proficiency in this course. There will be the opportunity to earn 155 points through the semester and grades will be assigned based on the percentage of points you earn out of the total points available.

0-59% Fail
60-69% D
70-79% C
80-89% B
90-100% A

I encourage discussion on all exercises, but I will not tolerate plagiarism. You are expected to turn in your own work and your own interpretation of the concepts and material. All work in this course must be completed in a manner consistent with NDSU University Senate Policy, Section 335: Code of Academic Responsibility and Conduct (http://www.ndsu.nodak.edu/policy/335.htm). Any work you complete in this semester that contains content copied from published material (web, journal articles, textbooks, alumni ANYTHING!!) or from another student will earn zero points.

Any students with disabilities or other special needs are encouraged to speak with Dr. Reed as soon as possible to make appropriate arrangements for accommodation

Below is a **tentative** schedule of topics to be covered over the semester

WEEK	TOPICS	MONDAY	WEDNESDAY	FRIDAY
JANUARY 1	**Evolution by Natural selection**		**13**	**15**
2		**18 Holiday**	**20**	**22** IBH Chapters 1-2
3	**Metabolism and Scaling**	**25**	**27**	**29**
FEBRUARY 4		**1** IBH Chapters 3-4	**3**	**5**
5	**Life History**	**8**	**10** IBH Chapters 5-6	**12 DARWIN DAY**
6		**15 Holiday**	17	**19**
7	**Energy Acquisition**	**22**	**24** IBH Chapters 7-8	**26**
MARCH 8		**1**	**3**	**5** IBH Chapters 9-11
9	**Energy Allocation Growth**	**8**	**10**	**12**
	Spring Break	**15**	**17**	**19**
10		**22**	**24**	**26**
11	**Energy Allocation Reproduction**	**29**	**31**	**2 Holiday**
APRIL 12		**5 Holiday**	**7**	**9**
13		**12**	**14**	**16**
14	**Energy Allocation Self Maintenance**	**19**	**21**	**23**
15		**26**	**28**	**30**
MAY 16		**3**	**5**	**7**
Exam Week		**10**	**12**	**14 scheduled 8-10am**

APPENDIX B. STUDENT HANDOUT DESCRIPTION FOR PORTFOLIO-OF-UNDERSTANING.

Portfolio of Understanding

A large portion of your grade (80%) will be based on the quality of evidence you provide demonstrating your understanding of the concepts explored in this course. Portfolios should be updated on a regular basis (at least weekly) as you prepare for, or reflect on, each class period. All entries in the portfolio **must** be dated with the date (day and month).

Portfolios must include the following 4 areas:

1. Inquiry
2. Lectures
3. Reflections
4. Literature

I will collect 10 portfolios **at random** each week (starting weeks 3 and 4 – I will collect 20 portfolios each of these weeks) to check for demonstration of understanding. You <u>must</u> bring your portfolio to class <u>every</u> class period. Failure to have your portfolio when called on for assessment will result in a 10% reduction in the final grade for that assessment period (if you know you are going to miss a class period send your portfolio with a friend or contact Dr Reed directly). Each section is worth 10.0 points at each evaluation.

1. Inquiry:
   a. At minimum this section must include questions you have regarding the material.
   b. Further evidence in this section could include posing hypotheses and predictions regarding the questions, attempts at answering your questions, creating potential exam questions and justifications of the answers, identification of misconceptions and preconceptions.

2. Lectures:
   a. At minimum this section must include all lecture notes and quizzes.
   b. Further evidence could include adding information from other sources (books, texts and primary literature) to your class notes, revision of incorrect answers on the quizzes, concept maps.

3. Reflections:
   a. At minimum this section must include your thoughts/reflections about the material presented in lecture or in the books/primary literature. These thought and reflection pieces should be done on a weekly basis and be about 1 page in length (typed, single spaced).
   b. Further evidence could include revisiting these reflections and identifying misconceptions or misunderstandings of the material, additional literature to complement the material covered in class.

4. Literature:
   a. At minimum this section must include all primary literature articles and evidence of reading (highlighting or notes in the margins…).
   b. Further evidence in this section could include answers to discussion questions, additional literature that complements the assigned literature.

During the 2nd, 3rd and 4th collection periods 5 additional points will be given for evaluation of your improvement of understanding as evidenced by documentation (written response) to the comments received in previous evaluations.

A minimum level of understanding is equivalent to a C grade (70%). Additional evidence presented will earn a B grade (80%) and the quality of the evidence (how thorough of an understanding you have evidenced by your ability to make connections among the concepts across the semester) can earn an A grade (90%). An A grade must be evidenced by creative thinking and the ability to synthesize and integrate material from the course.

APPENDIX C. INITIAL ASSESSMENT AND CONCEPTS IN PHYSIOLOGICAL ECOLOGY SPRING 2010.

Concepts in Physiological Ecology

Adaptation	Constraints	Symmorphosis
Fitness	Evolution	Osmosis
Natural Selection	Efficiency	Diffusion
Acclimation	Isometric	Acquisition
Phenotype	Allometric	Allocation
Genotype	Metabolism	Emergent properties
Phylogeny	Homeostasis	Life History
Trade-offs	Allostasis	

Biological Concepts I know	**Biological Concepts I sort of know**	**Biological Concepts I've heard of, but don't know**	**Biological Concepts I've never heard of before**

Concepts that group together

Definitions, examples and synonyms

Adaptation	
Natural Selection	
Acclimation	
Genotype	
Constraints	
Efficiency	
Allometric	
Homeostasis	
Symmorphosis	
Diffusion	
Fitness	

Metabolism	
Phenotype	
Trade-offs	
Evolution	
Isometric	
Allocation	
Phylogeny	
Allostasis	
Osmosis	
Emergent Properties	
Acquisition	
Life History	

APPENDIX D. INSTITUTIONAL REVIEW BOARD APPROVAL LETTER.

NDSU NORTH DAKOTA STATE UNIVERSITY

Institutional Review Board
Office of the Vice President for Research, Creative Activities and Technology Transfer
NDSU Dept. 4000
1735 NDSU Research Park Drive
Research 1, P.O. Box 6050
Fargo, ND 58108-6050

701.231.8995
Fax 701.231.8098

Federalwide Assurance #FWA00002439
Expires April 24, 2011

January 29, 2010

Dr. Lisa Montplaisir
Dept. of Biological Sciences
322 Stevens Hall

Re: IRB Certification of Human Research Project:

"Analyzing alternative assessments in science courses"
Protocol **#SM10164**

Co-investigator(s) and research team: **Brittany Ziegler**

Study site(s): **NDSU** Funding: **n/a**

It has been determined that this human subjects research project qualifies for exempt status (category # 1, 2) in accordance with federal regulations (Code of Federal Regulations, Title 45, Part 46, *Protection of Human Subjects*). This determination is based on the protocol form received 1/19/2010 and consent/information sheet received 1/19/2010.

Please also note the following:

- This determination of exemption expires 3 years from this date. If you wish to continue the research after 1/28/2013, submit a new protocol several weeks prior to this date.
- The project must be conducted as described in the approved protocol. If you wish to make changes, pre-approval is to be obtained from the IRB, unless the changes are necessary to eliminate an apparent immediate hazard to subjects. A *Protocol Amendment Request Form* is available on the IRB website.
- Prompt, written notification must be made to the IRB of any adverse events, complaints, or unanticipated problems involving risks to subjects or others related to this project.
- Any significant new findings that may affect the risks and benefits to participation will be reported in writing to the participants and the IRB.
- Research records may be subject to a random or directed audit at any time to verify compliance with IRB policies.

Thank you for complying with NDSU IRB procedures; best wishes for success with your project.

Sincerely,

Kristy Shirley

Kristy Shirley, CIP
Research Compliance Administrator

APPENDIX E. NARRATIVE EXPLAINING PROCESS OF CODING INITIAL AND FINAL ASSESSMENT EXAMPLES FROM TABLE 1.

The initial and final assessment coding rubrics categories were distinguished by the explanations provided by students and had a biological context. For example, the naïve response from Table 1 was coded as naïve because the response was incorrect (i.e. “to get something by touching the thing that has it”). As for the novice coding, in the example provided the response contains both correct and incorrect statements, and in this case is incomplete. The student is correct in that osmosis does involve “traveling across a membrane” however; the student is incorrect in stating that “fluids” do this because in osmosis it is a specific fluid. The response is also incomplete because there is no explanation of how the fluid travels or moves through the membrane. As for the intermediate response the response is technically correct, osmosis is as the student states “diffusion of water” however, the statement is not complete because the student does not specify what the water is diffusing across or through. The advanced example, is correct and complete, the student fully describes that osmosis is the diffusion of water and it passes “through a semi-permeable membrane”

APPENDIX F. CODING RUBIRC FOR STUDENT REFLECTIONS.

	Inadequate	Naïve	Novice	Intermediate	Advanced
Relevancy	Not relevant, is based primarily on summary of class	Majority is summary of class notes and is primarily based on facts	May contain summary of notes or class and facts but isn't the majority of reflection	Majority may contain summaries but only of supplemental material and few facts	Contains no summary and develops ideas beyond facts
Application, Conclusions, and Inferences	No attempt to demonstrate application, draw conclusions, interpretations or inferences	Attempts to apply content, draw conclusions, interpretations or inferences but is inaccurate	Attempts to apply content, draw conclusions or inferences, interpretations but are weak and may be unwarranted	Applies content, draws conclusions, interpretations or inferences that are accurate but may lack confidence and are limited in depth	Applies content, draws conclusions, interpretations and inferences that are warranted, accurate or insightful
Conceptions	Work too vague or incoherent for reader to determine	Based primarily on preconceptions	Contains minor preconceptions and/or inaccuracies	May contain a preconception or inaccuracy but isn't foundation of reflection	Contains no preconceptions or inaccuracies
Examples, Evidence, and Supplemental Material	No attempt of support	Attempts to utilize examples from personal experience but may be inaccurate or fails to connect examples to previous learning	Utilizes few examples, evidence or supplemental material but only as verification	Utilizes examples, evidence or supplemental material to support previous learning but make lack confidence, depth or thoughtfulness	Utilizes examples, evidence and supplemental material to support previous learning
Interconnectivity	No attempt to connect content to previous experiences or learning	Inaccurately attempts to demonstrate connections to previous personal or learning experiences	Weak or limited attempts to demonstrate connections to previous personal or learning experiences	Demonstrates ability to make connections from other courses and personal or learning experiences but lacks confidence, depth or thoughtfulness	Demonstrates confident ability to draw insightful and thoughtful connections between previous personal or learning experiences

APPENDIX G. NARRATIVE EXPLAINING PROCESS OF CODING REFLECTION EXAMPLES FROM TABLE 2.

For the example of the reflection in Table 2 coded as inadequate, it was coded as inadequate because the reflection did not contain any information relating to course content, because of the lack of content; there is no attempt to demonstrate application, conclusions or draw inferences based on content. As for the naïve reflection example, it was coded as naïve because the majority of the reflection is based on fact (i.e. "constraints provide restrictions or limitations"). The information provided is too vague to determine what the students' conceptions are about the content. The reflection does not contain support however; the student does attempt to connect content (i.e. "genetic constraints, developmental, mechanical, phylogentic, and physiological constraints"). Ultimately, though the majority of the reflection is based upon factual information and weak connections. The connections do not to connect material to previous learning or experiences and stems from the factual information provided in the first sentence. This contributed to the reflection being coded as naïve, as it was interpreted that the connections made were related to the previous fact stated which was at a naïve level. For the reflection coded as novice, the key aspects of the reflection, include that the majority of the reflection is not based on a summary of notes, however, the student also does not fully develop his/her ideas. This is seen when the student states "...I would think that there are several other exceptions..." but does not expand on what those exceptions may be. The conception that the student has of the method discussed reflects a lack of understanding why this method is important in biology (i.e. "...I don't understand where it could be useful in biology"). The student does provide a single example to verify why he/she believes this method is not useful (i.e. "You cant [sic] do it with growing animals..."). It is based on this that the student's reflection aligns with a novice category of the coding rubric. In the excerpt highlighting a reflection coded as intermediate, the student does develop ideas beyond summarizing class notes and utilizes supplemental material, (i.e. “The Romero, L.M. et al. paper that we read in class”) however, the student does not explain how or why the paper aided in the their understanding or provide any information related to the paper. In addition, the paper was read to as part of the course not one the student researched to support their understanding. The students does articulate a connection between allostasis and reproduction and provides an example (i.e. “For example, consider those individuals who are income breeders”). The conclusion reached from this example is limited (i.e. “that individual would undoubtedly become stressed out”) but the student fails to expand beyond this. The final reflection was coded as advanced because although the reflection does contain factual information (e.g. definitions of allostasis) the student presents these definitions as a means to evaluate their appropriateness (i.e. “...I think a better definition is...). This student utilizes supplemental material that he/she researched about the connections between fitness, natural selection and allostasis. The student provides information and examples from the article (i.e. “This article is focusing on the idea that allostasis has something to do with ones tolerance to alcohol”) and draws accurate and in depth inferences from the article and examples provided (i.e. “The allostasis that is taking place is exactly what we are defining. Both a dependence and a tolerance are clear ways to adapt to survive in a way”), which led to it being classified as an advanced reflection.

APPENDIX H. DETAILED METHODS

Research Context

Portfolio-based assessment was implemented in a three-credit, upper-level biology course, that met three times weekly and covered physiological mechanisms underlying life-history trade-offs and constraints in an ecological and evolutionary context. The only prerequisite for this course was a semester of introductory "organismal" biology lecture and laboratory. The main topics covered in the course include evolution, energy acquisition, life history, metabolism and scaling, homeostasis and allostasis, and energy allocation to growth, reproduction and self-maintenance. IRB approval was #SM10164 (Appendix D).

Instruction for the course was lecture-based with students required to develop a *Portfolio-of-Understanding*. The Portfolios-of-Understanding were composed of four components: reflection, inquiry, lecture notes, and primary literature, all of which were designed by the instructor (Appendix B). Working within the context of the course two aspects of the Portfolio-of-Understanding were analyzed, the student written reflection and inquiry questions. Minimum weekly contributions to each section were required for the course. Therefore, each student should have submitted 14 inquiry questions and 14 one-page reflections. The reflection and inquiry components of student portfolios were chosen for analysis because these components gave students the opportunity to reflect on, pose questions about, apply, and demonstrate their knowledge. In their reflections, students could demonstrate further evidence by revisiting and identifying misunderstandings in previous reflections as their understanding developed (Appendix B). The inquiry component gave students the opportunity to pose questions. Further evidence for the inquiry component could include creating hypotheses, making predictions, and attempting to answer their own questions (Appendix B). We expected that there would be a significant relationship between reflection quality and cognitive level of inquiry questions and both would be significantly related to student final grade. Students' maintained their portfolios electronically in Spring 2010. By maintaining their portfolios electronically students were not encumbered by being required to bring their portfolios to class and also maintaining portfolios electronically allowed students to take advantage of electronic resources.

The instructor assessed each student's work four times over the semester and could have provided feedback. Students who demonstrated evidence of improved understanding in response to instructor comments from previous evaluations were given additional points (Appendix B). Although the assessment method implemented had the same components and outcomes in each semester, the collection methods for semesters differed. In Spring 2010, students' portfolios were collected based on a predetermined schedule with students knowing in advance when their portfolios would be collected and evaluated. In Spring 2010 a subset of students' portfolios were collected weekly. Student portfolios were the primary form of assessment. In Spring 2010, student portfolios composed 88% of a students' final grade (Appendix A).

Students completed an initial assessment in which they were required to define, provide examples or synonyms for biology concepts and terms as well as indicate which concepts were related to each other (Appendix C). Students also completed a take home final at the end of the semester, which was formatted as a paper or essay; students were again required to demonstrate their knowledge about the concepts from the initial assessment.

This course caters to both undergraduate and graduate students. For the purpose of this study, only undergraduate students were included. In Spring 2010, 28 students participated in the study agreeing to allow access to their coursework. Only participants who completed the course, as determined by students who received a final grade, were included in analysis.

In addition, GPA data could not be retrieved for two students enrolled in Spring 2009 and 1 student enrolled in Fall 2010. There were substantially more seniors enrolled in the course with 83% of the students being seniors and 89% were Zoology majors.

Data Collection

We decided to analyze the reflection and inquiry sections of student portfolios because student reflections provided opportunities for students to demonstrate reflective thinking while student questions can be a potential resources for students to learn science (Chin and Osborne 2008). A rubric was developed for this study independent of the course to determine quality of students' reflections. The rubric to determine quality of student reflections consists of five levels and each has clear criteria (Appendix E). The reflection rubric criteria emerged after analyzing reflections and literature concerning reflections and their evaluation, characteristics of reflecting and critical thinking, and consists of factors deemed part of critical thinking (Bailin 2002). In addition, the rubric was developed based upon criteria that emerged from student reflections, which highlights effective means to develop rubrics (Wiggins and McTighe 2005) and portfolio-of-understanding requirements (Appendix B). For example, an implicit goal of the portfolios-of-understanding was to foster student growth in understanding the interconnectivity of biology fields and concepts (Appendix B). Therefore, whether or not students connected content was an important factor in the reflection rubric. The rubric went through a development process, with multiple iterations, until the final version was developed which effectively assessed student reflections for the attributes we were interested in. For the purposes of analysis, two researchers independent from the course individually coded student reflections for Spring 2009. The researchers coded 65 reflections from five students and discussed any disagreement in scores until each was resolved. Then one researcher continued to code student reflections independently (n = 1385). The coding process underwent an iterative development in which our goal was to reach 100% inter-rater agreement. In addition, the second researcher repeated the coding process by randomly selecting previously coded reflections to code again to ensure intra-rater agreement. During the scoring process, anchor papers were used as examples of reflections that met each criteria level of the rubric to help ensure repeatability and agreement. If reflections contained attributes from different rubric categories, each was coded into the category in which it best aligned.

Questions posed in students' inquiry component were coded using Bloom's taxonomy (Krathwohl 2002) to determine student level of cognitive thinking. We applied Bloom's Taxonomy to determine the cognitive level of student questions for multiple reasons. Firstly, the instructor provided handouts to students at the beginning of the course, which provided examples of questions that were expected to be part of their inquiry section that highlighted the categories of Bloom's Taxonomy (Appendix 10). Secondly, Bloom's Taxonomy is a theoretical model that classifies questions based upon the level of thought that is required from them to be answered (Chin and Osborne 2008). The original Bloom's Taxonomy was developed with six categories (knowledge, comprehension, application, analysis, synthesis, and evaluation) (Krathwohl 2002). These categories are often divided into what are term low cognitive levels (knowledge and comprehension) and high cognitive levels (application, analysis, synthesis, and evaluation).

Bloom's taxonomy was originally developed to facilitate communication and as a means to determine the congruence of objectives and assessments (Krathwohl 2002) but it can also "be applied to students' questions" (Chin and Osborne 2008). Even though, Bloom's Taxonomy is highly applicable there are limitations to this cognitive hierarchy. It may be oversimplified and because it is represented as a hierarchy it implies that the higher skills are composed of the skills beneath it. Under this assumption, individual cannot achieve evaluation without first achieving apply or application. Research has centered on studying whether or not Bloom's taxonomy is a cumulative hierarchy (Anderson and Krathwohl 2001). In a meta-analysis by Anderson and Krathwohl (2001), data supports that the ordering is hierarchical for the middle categories and is best supported when knowledge is excluded. Therefore, the cumulative hierarchy was only slightly supported in their study. Arguments over whether or not the top two categories should be reversed however may depend on the view of what the top categories should represent (Anderson and Krathwohl 2001). Although, Anderson and Krathwohl contend that synthesis is cognitively more complex than the evaluate category they state "there is weak supportive empirical evidence for Synthesis (now *Create*) as the highest category." For the purposes of this study we maintained evaluate at the highest category.

Two independent researchers independently coded approximately 5% of student inquiry questions based upon Bloom's Taxonomy. Any differences in coding were discussed until each was resolved and then one researcher continued to code students' inquiry component. The coding process was underwent an iterative development in which 100% agreement was the goal. In addition, the second researcher repeated the coding of inquiry by randomly selecting previously coded questions to code again to ensure intra-rater agreement. During the scoring process, anchor papers were used as examples of each level of Bloom's Taxonomy that met each criteria level to help ensure repeatability and agreement. If a question contained components from different levels, it was coded at the highest level of cognition reached.

For analysis, the reflection rubric and levels of Bloom's Taxonomy were converted to an ordinal scale. While reflections were evaluated for quality and inquiry questions for cognitive level, the researcher indicated whether feedback from the course instructor was provided on student reflections and inquiry. Reflections that were not relevant to course content were not included in analysis (Spring 2010). These reflections included the first and/or last reflection from students and included students discussing difficulties with technology required to maintain a portfolio, expectations or feelings about portfolio-based assessment, and summarizing thoughts about their course experience (For examples of student reflections not included in analysis, see Appendix I).

References

Anderson, L. W. and D. R. Krathwohl (Eds.)., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., and M. C. Wittrock. 2001. Empirical studies of the structure of the taxonomy. In *A Taxonomy for Learning, Teaching and Assessing,* (287-331). New York: Longman.

Chin, C. and J. Osborne. 2008. Students' questions: a potential resource for teaching and learning science. *Studies in Science Education, 44,* 1-39.

Krathwohl, D. R. 2002. A revision of bloom's taxonomy: An overview. *Theory into Practice, 41,* 212-264.

APPENDIX I. EXAMPLES OF STUDENT REFLECTIONS NOT INCLUDED IN ANALYSIS.

Week 15 Reflections

What Physiological Ecology taught me

Since this is the last official week of class, I would like to devote my last reflections to looking back at this semester and observing what I have learned. The major difference that I see is in reading scientific papers. Before this class I only read journals when I had to, and even then I dreaded the many pages of technical language that I would have to endure. However, after reading a paper or so each week, I have become more comfortable with reading and understanding the figures and graphs. I have even willingly included papers for each week to enhance my understanding of a certain topic. Plus, now that I understand more of the ecological terms relating to animals and their behaviors, it is a lot easier to understand what the author is studying.

I do regret that I have not learned how to interpret words and turn them into graphs. I do understand the difference between allometry and isometry but if you give me a relationship, I still cannot transfer the sentence into a graph on paper. Hopefully by taking more scientific classes, I will have mastered this skill and be able to use it in my future career someday.

I think this class has also taught me to look at the world in a different way. Before coming into this course, my main goal was to just study mammals and the behavior they exhibit. However, after being taught physiological ecology by an ornithologist, I have developed a better appreciation for other forms of life including birds and invertebrates. I am now interested in studying ecology as a whole, how animals interact with each other and also their environment. I feel this class has been vital to my learning and I would have been lost in a science career without it.

-Student 1, Spring 2009

Reflection #14: A Reflection of the Semester

As the end of the semester comes down to a close I find myself reflecting on all that I have learned in the past 4 months in my courses. I can come up with random facts, interesting research, and "tid-bits" that I can share with my family, but most of all, I have learned to think with a more "well-rounded" point of view. I was talking about this very topic with my friend. I told her that for the first time this semester, I feel that I can truly think critically. I find myself asking questions that I wouldn't normally have taken the effort to think of or even been interested in. I feel that in my first two years of college, it was mostly about just memorizing. Now, I feel that I have enough background information that I can finally start tying all of it together. For instance, I am able to relate physics to general chemistry. In physics I learned that the electric field formula indicates that the larger the radius, the smaller the electric field force. This directly correlates to the fact that valence electrons on the outer shell (farther away from the nucleus) are lost more readily because there isn't as strong of a force tying them to the nucleus. Also, I am able to relate organic chemistry to biology. In organic chemistry, we learn all the reactions of carboxylic acids and that they have polar heads and non-polar tails (due to unequal electron sharing). This relates the reason why micelles are formed of fats with the help of bile salts. As for physiological ecology, I think you may have noticed that I am most eager to relate it to psychology. Never before in my science courses have I been given the opportunity to actually share my thoughts on relating courses. That is why I believe the portfolio was such a good idea. I am able to show my understanding in various ways. I work on my portfolio every Monday, Wednesday, and Friday afternoon. I first organize my notes and rewrite them in ways that one might actually comprehend (for example, fewer arrows going every which way). I then put on paper any questions that might have crossed my mind during lecture. I then think about possible answers and communicate those ideas as well. Also, every weekend, I would read a literature article that gave a new spin to the lecture. This too helped in my understanding of the course content because reading that material is more active learning. It is not the same as just sitting back in class and the professor "talking at" us. Then we get to discuss or thoughts and feelings with our classmates. This helps us gain new insight and points of view, contributing even more to my more "well-rounded" thinking. Once a week, I feel that I have enough information to tie things together in a reflection. This is when I could tie in my psychology to my physiological ecology. I felt that the portfolio of understanding facilitated my transition of thinking about my college courses. It led me to a more "tie everything together" mindset. I believe that becoming a successful doctor involves being able to approach a situation from multiple points of view.

I will end this last reflection with one more interesting concept shared between psychology and physiological ecology. Research in psychology has shown that a network of family, friends, neighbors, and community members that are available in times of need to give psychological, physical, and financial help is related to a decreased chance of catching a cold. This is due to the social network helping the person cope with stress, therefore, increasing their threshold of going into emergency life history stage. ☺

- Student 121, Spring 2010

Week of 8/23/2010 to 8/27/2010

Reflections:

After discussing the format of this course I feel like it will be very difficult for me. I typically prefer classes without homework that rely heavily on tests for grades. I am not good at keeping myself on top of course material at every point in time. I tend to get caught up in the next thing that is due and don't make time to review each subject daily or even weekly sometimes. I usually begin studying about a week before the test and then when the pressure is on I do well motivating myself to get what I need to do finished. I find that I work most efficiently under pressure. Therefore to remedy this bad habit of mine, I am going to try to envision this course as having weekly tests. It will be a test demonstrating my understanding of the concepts we have learned that week. It would be very difficult to remember specifics about the lectures if I procrastinated until near the point of the due date so if I can keep this mindset I may actually feel pressure to keep caught up with my portfolio entries. I have set aside three hours during the week for working on my portfolio and I will spend as much time on Sunday afternoons as necessary to get my portfolio done well. I also found an hour to set aside for asking questions. I feel that going over the lecture material that I don't understand will be imperative to doing well in this course.

Since I am determined to get an A, I will have to be creative as to what is in my binder for extra materials and to make sure that my reasoning and logic is always sound. Right now I am feeling overwhelmed by the course but I know that I will just do my best and work with the feedback that I get back from my previous portfolio checks. You're doing great! I apologize for being so slow on getting feedback to you!

The part of the portfolio that I am most concerned about is making sure that each of the seven general concepts and the 24 concepts are covered in each section of the portfolio. I would love some feedback about the best way to make sure that I have this covered.

On the other hand, I may be good at the portfolio because one of the best ways for me to gather thoughts effectively is through writing. If I am called on unexpectedly in class my mind does not allow me to form any type of intelligent response whereas if I can think of what I am trying to say and edit it I can usually portray my understanding of the material.

Course Goals:

- To keep on top of my tasks each week and finish each weekly portfolio section before the Monday of the next week.
- To find creative ways to add to my portfolio that helps my individual learning style
- To put in enough effort to deserve an A in the course

- Student 53, Fall 2010

APPENDIX J. SPRING 2009 COURSE SYLLABUS.

Spring 2009
Physiological Ecology 462
MWF 11:00-12:50, 230 Stevens

Dr. Wendy Reed, Wendy.Reed@ndsu.edu
Office: Stevens 311, office hours any open time, I post a schedule of my weekly schedule on my office door, please stop by my office and sign up for an open time that works with your schedule.

Readings: We will be reading a couple of books over the course of the semester, as well as articles from the primary literature. Any general physiology textbook will serve well if you need a reference.

Required books: Currently I have made a decision about one book and am deliberating about another…..the book we will definitely be reading is below, stay tuned for more information….

In the beat of a heart. Life, energy and the unity of nature. John Whitfield. 2006. Joseph Henry Press. *This book is available online. There is a website for the book (http://www.inthebeatofaheart.com/) with links for purchase options. You can read the entire book online for free, purchase a downloaded pdf version, or purchase a hard copy. Keep track of this website, there are useful updates and information regarding the topic of scaling in biology and it might be helpful for discussions.*

Recommended Physiology Textbooks: These are books that provide a good reference, they are not required for the course, but will provide additional background if you feel like to need more information.

Wilmer, Stone and Johnston. 2005. Environmental Physiology of Animals. 2nd edition. Blackwell Publishing.
Hill, Wise and Anderson. 2004. Animal Physiology. Any edition. Sinauer Publishing. *this is the same text used in Zoology 460.

Attendance: You are encouraged to attend class, but attendance is not mandatory. You are expected to be in class on time. If you are going to be late, do not interrupt class. Please make arrangements to get notes from a classmate.

Course Description: Study of the physiological mechanisms underlying life-history trade-offs and constraints in an ecological and evolutionary context.

Course Objectives: At the end of the course I expect students will have accomplished the following goals:

1. Become familiar with the basic terminology and concepts in physiological ecology
2. Gain an understanding of physiological adaptation and evolution by natural selection
3. Gain the ability to synthesize information from the primary literature with an emphasis on graphs

The exercises I have selected are designed to help you accomplish these goals.

Evaluations:
You will have the opportunity to earn 215 pts over the course of the semester.

Portfolio (175 pts): You will be building a portfolio of understanding over the course of the semester. The portfolio will be evaluated 4 times during the semester (40 pts first evaluation, 45 pts 2nd, 3rd, and 4th evaluation), at approximately 4-week intervals. A rubric will be provided.

Quizzes: (8) 5 pts each = 40 pts. Quizzes will cover material from the readings and lectures.

Grading Policy
I will not give you a grade; you are responsible for earning your grade by demonstrating proficiency in this course. There will be the opportunity to earn 215 points through the semester and grades will be assigned based on the percentage of points you earn out of the total points available.

0-59% Fail
60-69% D
70-79% C
80-89% B
90-100% A

I encourage discussion on all exercises, but I will not tolerate plagiarism. You are expected to turn in your own work and your own interpretation of the concepts and material. All work in this course must be completed in a manner consistent with NDSU University Senate Policy, Section 335: Code of Academic Responsibility and Conduct (http://www.ndsu.nodak.edu/policy/335.htm). Any work you complete in this semester that contains content copied from published material (web, journal articles, textbooks, alumni ANYTHING!!) or from another student will earn zero points.

Any students with disabilities or other special needs are encouraged to speak with Dr. Reed as soon as possible to make appropriate arrangements for accommodation

Below is a **tentative** schedule of topics to be covered over the semester.

WEEK	TOPICS	MONDAY	WEDNESDAY	FRIDAY
JANUARY 1	Evolution by Natural selection		14	16
8B 2	Metabolism and Scaling	19 Holiday	21	23 IBH Chapters 1-2
3	Nuts and Bolts	26	28	30
FEBRUARY 4	Homeostasis and Allostasis	2 IBH Chapters 3-4	4	6
5	Life History	9	11 IBH Chapters 5-6	13 No Class
6		16 Holiday	18	20
7	Energy Acquisition	23	25 IBH Chapters 7-8	27
MARCH 8		2	4	6 IBH Chapters 9-11
9	Energy Allocation Growth	9	11	13
	Spring Break	16	18	20
10		23	25	27
APRIL 11	Energy Allocation Reproduction	30	1	3
12		6	8	10 Holiday
13		13 Holiday	15	17
14	Energy Allocation Self Maintenance	20	22	24
15		27	29	1
MAY 16		4	6	8 Final Portfolios Due in class.

APPENDIX K. NARRATIVE EXPLANING PROCESS OF TRANSFORMING CONCEPT WEB IN FIGURE 4.

Concepts that were included in this concept webs emerged from the student's reflection. The students entire reflection follows:

"*On the first day of class we were asked to fill out a worksheet on the concepts in physiological ecology. As I was doing this a lot of terms that I thought I had a good understanding of I didn't think I had a good of understanding anymore. I recognized many of the terms, but did I really understand what they meant. I know that* ***adaptation*** *is an* ***evolutionary*** *process of change, but I didn't know that it was in the genotype over a long period of time like generations. Acclimation was a word that I sort of knew, but I didn't know that it was an animals response over a shorter period of time, like how we in North Dakota are* ***acclimated*** *to the cold, but in the summer we are* ***acclimated*** *to the hot* ***environment****. I thought that a phenotype was just an expressed observable trait, but its more than that. Its* ***morphology****,* ***physiology****, and* ***behavior****, and they all reflect each other.* ***Genes*** *and the* ***environment*** *play an important role on* ***phenotype****. The reading, Is Extreme Bite Performance Associated with Extreme Morphologies in Sharks?, was interesting. It was surprising to me that larger sharks don't bite hard for their size, but sharks with larger heads bite harder. It was also surprising to me that sharks with relatively high bite force have more pointed teeth, because they have a stronger bite force I wouldn't think that they need a pointed of teeth compared to a shark with low bite force. I thought that a shark with low bite force would need pointed teeth to pierce through their prey. This reading was a good example of how* ***behavior*** *and* ***morphology*** *reflect each other in a* ***phenotype****. The behavior of how strong bite force is based on the morphology* *factor of how wide its head is."*

The concepts are included in the concept web are bolded. Relationships between concepts from the reflection were included when the student described how different concepts are related, influenced by, or involved with other concepts. For example, the student states, "I thought phenotype was just an expressed observable trait, but it more than that. Its morphology, physiology, and behavior..." This statement was transformed into the concept web by having a relationship between phenotype to morphology, physiology, and behavior. The last sentence "The behavior of how strong bite fore is based on morphology factor of how wide its head is" was not included as a relationship between morphology and behavior. The size of the animal's head that is being referred to is a phenotypic feature. This sentence was interpreted as being a continuation of the previous sentence (i.e. "this reading was a good example of how behavior and morphology reflect each other in a phenotype) in which morphology and behavior are linked through phenotype. This relationship is included in the concept web.

APPENDIX L. INQUIRY EXAMPLE STUDENT HANDOUT.

Summary and Definition Questions – Avoid these, these kinds of questions do not meet the minimum requirements

what is (are)...?
who...?
when...?
how much...?
how many...?
what is an example of...?

Analysis Questions

how...?
why...?
what are the reasons for...?
what the types of...?
what are the functions of...?
what is the process of...?
what other examples of...?
what are the causes/ results of...?
what is the relationship between ...and ...?
what is the similarity or difference between... and...?
how does ...apply to ...?
what is (are) the problems or conflicts or issues...?
what are possible solutions/ resolutions to these problems or conflicts or issues...?
what is the main argument or thesis of...?
how is this argument developed...?
what evidence or proof or support is offered...?
what are other theories arguments from other authors...?

Hypothesis Questions

if...occurs, then what happens...?
if ...had happened, then what would be different...?
what does theory x predict will happen...?

Evaluation Questions

is...good or bad...?
.....correct or incorrect...?
.....effective or ineffective...?
.....relevant or irrelevant...?
.....clear or unclear...?
.....logical or illogical...?
.....applicable or not applicable...?
.....proven or not proven...?
.....ethical or unethical...?
what are the advantages or disadvantages of...?
what are the pros or cons of...?
what is the best solution to the problem / conflict / issue...?
what should or should not happen...?
•do i agree or disagree ...?
what is my opinion...?
what is my support for my opinion...?