Examining integrative thinking through the transformation of students’ written reflections into concept webs

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After years of education focused on isolated discrete knowledge, 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 to gain insights into how students connect biological concepts. We were interested in determining if characteristics of integrative thinking develop through reflections. The results indicate a significant relationship between concepts and integrated relationships. Integrative thinking varied but declined overall. Concept webs allow for an examination of student integrative thinking through the transformation of reflections and provide insights into the connections and relationships that students draw between biological concepts. Reflections can transform learning by facilitating and allowing for the evaluation of integrative thinking.

Integration 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 (19), draw connections (17), and interpret, incorporate, and relate new knowledge with prior knowledge (9, 23). Integrative thinking potentially makes learning science difficult, as biology requires students to integrate concepts across levels of organization to synthesis and analyze content (2). A study (24) examining undergraduate physiology student problem-based writing with peer review found that students have difficulty relating concepts and problems recognizing organizational levels. 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 (17) as meaningful learning starts with the construction of mental models or representations of knowledge (19).

To facilitate students’ drawing connections between content, there is a need not only to develop assessments that foster integration (10) and to determine how prevalent student difficulties in determining relationships (24) but also allow for integrative thinking to be effectively evaluated. Reflections used in portfolios provide a means to support integrative and connected learning (10). Reflections can provide an opportunity for students to connect content (12) as analytical writing can be a means for students to transform ideas into structured and coherent knowledge (27). Quality reflections have been found to be composed of multiple characteristics, including drawing connections between content, previous learning, and experiences (12, 32). Previous research analyzing student reflections have commonly examined the quality of reflective thinking or writing (26, 31, 32). This study was designed to develop a method in which student integrative thinking could be evaluated. Developing a method that allows for insights into how students draw relationships between content can help in understanding how students potentially integrate knowledge and may provide insights into how integrative thinking can be fostered in students.

The primary component of assimilation learning theory is meaningful learning (3), which is the foundation of constructivism (21). Meaningful learning, as described by Ausubel (3), is a process where ideas are expressed in a nonrandom and nonverbatim way that is relevant to students’ current knowledge structure and has the potential to be learned meaningfully. 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 (23). When new information generates a connection with prior understanding and experience, it can help to reinforce, break down, and reconstruct relationships (14). Ausubel (3) explained 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 con-
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 3 times/wk and covered physiological mechanisms underlying life history trade-offs and constraints in an ecological and evolutionary context. The course emphasized building on previous coursework to understand complex concepts and connections across biology. One of the main learning objectives of the course was for students to recognize and understand relationships between concepts. While the only prerequisite for this course was a semester of introductory “organismal” biology lecture and laboratory, the majority of students comprised 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 assessments supplemented with reading quizzes. Student portfolios accounted for >80% of the student’s final grade. This study coincided with the first semester portfolio-based assessment as was implemented by the instructor. Student portfolios were composed 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 any time, independent of when lectures occurred, but at a minimum, weekly contributions to each section of the portfolios were 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. Students were encouraged to revisit and expand previous reflections as their understanding developed. One aspect in which student portfolios were graded was based on the 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.

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 male and female students (21 male students and 20 female students). The Institutional Review Board approved this study (approval no. SM10164).

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. These concepts included isometric, allometric, metabolism, osmosis, acclimation, and emergent properties in addition to others. This activity provided researchers guidance in determining the concepts that were likely to emerge while transforming student reflections. The concepts included in concept webs emerged based on those used in student reflections. For the purposes of analysis, two researchers, independent of the course, retroactively transformed student reflections into what we termed concept webs. Any disagreements were discussed until each was resolved, and one researcher then continued to finish transforming student reflections. The methods used in the transformation process were adapted from those outlined by Novak (20). This study developed a mix-mode method that combined the advantages of different visualization tools (8). Specifically, our methods differed from those of Novak (20, 21), who transformed interview data into concept maps with a hierarchical top-down format and reading direction. Rather, we followed the contention outlined by Herman et al. (9), who stated that learning is not linear and therefore does not proceed in distinct hierarchies. Based on 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 structure of knowledge (1). We also did not place an emphasis on the validity of concepts and relationships, which differs from another study (23) using concept maps. 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 (13). Therefore, 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 with expert concept webs. The following examples from students’ reflections show how student written reflections were transformed into concept webs (Figs. 1–3): SP: the student information should be justified to the right and the font size should match that of the quote above.

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, paracrine, 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]

. . . 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 (positive [sic] Allometry). Scaling Larger animals have greater absolute metabolic need than smaller ani-

Fig. 1. Example of a student’s reflections transformed into a concept web.

- Homeostasis
- Growth
- Physiology
- Reproduction
- Hormones
- Phenotype

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mals. 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 1 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.

...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 ...

Analysis. Concepts were included in a web not only if a student used the term explicitly but also if the student inferred 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 were analyzed collectively. Relationships could link two concepts together or link a relationship and concept. Relationships and concepts from all concept webs were included for analysis. It was not our goal to examine the 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 shown in Fig. 4 contains 13 concepts and 12 relationships. When the relationships were examined more closely, 10 relationships (represented by solid lines) indicated relationships between two concepts. The other two relationships (represented by dashed lines) indicated that a student recognized that the interaction between two concepts could be linked to another concept. For example, the student shown in Fig. 4 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. (16) by determining the number of relationships per concept present. Therefore, the interconnection ratio shown in Fig. 4 is 0.92. If interconnections could not be calculated, they were excluded from analysis. All concepts from student reflections were included when transformed into concept webs even if no relationships were associated with it. These concepts were referred to as isolated concepts. There are no isolated concepts shown in Fig. 4.

There were substantial differences in student concepts webs; however, a normal distribution existed for mean interconnections (goodness of fit – $W = 0.9864 \ P < W = 0.8977$). This suggests that integrative thinking falls along a continuum.

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 (means ± SD: 5.1165 ± 3.4131) than relationships [means ± SD: 3.3750 ± 3.6394], and the mean interconnection value was $0.6083 \ (± 0.3155)$. There was a significant relationship between the number of concepts and
relationships ($F_{1,471} = 4582.47, P < 0.0001, R^2 = 0.8352$), 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 present and accounted for $<1\%$ of the concepts present. The mean number of relationships connected to a concept was 1.340 ($\pm 1.018$), with allocation (mean $\pm$ SD: 2.1373 $\pm$ 1.3714), phenotype (mean $\pm$ SD: 2.0492 $\pm$ 1.5103), and genotype (mean $\pm$ SD: 1.8235 $\pm$ 1.1438) garnering, on average, the most relationships. Osmosis did not garner any relationships (Fig. 5), and relationships to emergent properties (mean $\pm$ SD: 0.250 $\pm$ 0.500), isometric (mean $\pm$ SD: 0.5 $\pm$ 0.5189), and allometric (mean $\pm$ SD: 0.6897 and 0.8495), on average, garnered the fewest relationships.

There was an overall drop in concepts, relationships, and interconnections over the duration of the course; however, substantial variability existed (Figs. 6 and 7). Mean concepts for the 4 wk varied significantly ($F_{3,104} = 11.2360, P < 0.0001$). There were also significant differences between relationships in concept webs from different weeks ($F_{3,104} = 7.0693, P = 0.0002$) and

Fig. 4. Example of a concept web.

Fig. 5. Example of a concept web showing isolated concepts.
interconnections ($F_{3,99} = 2.6927, P = 0.0502$). When concept webs were examined from the first 4 wk compared with those after week 10, again there were significant declines in concepts ($F_{1,251} = 13.5416, P = 0.0003$) and relationships ($F_{1, 251} = 8.7205, P = 0.0034$) but not interconnections ($F_{1,240} = 3.8335, P = 0.0514$). When student concept webs were matched from the first 4 wk to those after week 10, 24.4% had an increase in relationships, 14.6% had an increase in concepts, and 19.5% had 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. (16), who examined the restructuring of undergraduate students’ knowledge in biology and found that concepts and relationships increased, whereas 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 (16) while focusing on specific topics as the course progressed.

In addition, the decline may be explained by students struggling to integrate concepts into their existing knowledge frameworks. It is assumable that certain concepts are easier or more difficult for students to integrate than others, 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, as shown in Fig. 2, with a rate of interconnections that is within the upper quartile, but that does not necessarily mean students do not still struggle with integrating certain concepts. In the case of the student’s reflection that is transformed in Fig. 2, there are still multiple concepts that are isolated. This could provide insights 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 insights into student thinking. If student concept webs contain a high number of concepts with relatively few relationships, this may suggest that students are using rote-learning approaches (16).

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 with other students. This distinction may be of importance because to learn meaningfully, students need to possess background knowledge (22). It does not appear as though that students are incapable of integrating knowledge, but some may have a narrower foundation of knowledge on which to integrate.

**Conclusions.** 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 insights into integrative thinking, we examined concept webs transformed from students’ written reflections. This study developed a mix-mode method that combined the advantages of different visualization tools (8). The type of visualization used in this study combined multiple visual formats, which we found to be beneficial and effective for determining student integrative thinking as well as the 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 (8); these features were incorporated into our concept webs. However, our concept webs were not organized hierarchically, were not compared with expert representations, and were not formed to answer a specific question, which are characteristics of concept maps (22). The concept webs developed in this study may provide an authentic visualization of student knowledge because student reflections were not written to answer specific question or to demonstrate a potential expert level of understanding.

Although it has been argued that the main benefit from concept maps is accrued to the person who constructs them (21), our approach may be beneficial as a research model for researchers investigating students’ written reflections and for examining students’ ability to integrate knowledge. 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. This model describes the nature of student knowledge of biological concepts and may be informative in helping to guide students through the transition process of moving along the integrative thinking continuum. 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 insights into whether students are meeting learning goals.

To understand student integrative thinking, we need to understand how their knowledge is structured (7). This study represents a step forward in developing methods that can be used to assess and enhance students’ integrative thinking to guide students further along the continuum of integrative thinking, but more research is necessary. Examining assessment methods is extremely valuable because it can help in transforming biology undergraduate education (2). Connections are an integral part of learning, and the development of 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 insights into how student think and develop an understanding about complex biological phenomenon through the use of transforming students’ written reflections into concept webs.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: B.Z. conception and design of research; B.Z. performed experiments; B.Z. analyzed data; B.Z. interpreted results of experiments; B.Z. prepared figures; B.Z. drafted manuscript; B.Z. and L.M. edited and revised manuscript; B.Z. approved final version of manuscript.

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