Appendix 1: The 5CCs as used in this study (as mentioned in Chatzikyriakidou et al., 2021)

| Core Concept                      | Main description                                                                                       | Importance in biology                                                                 |
|-----------------------------------|-------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Evolution (E)                     | The diversity of life evolved over time by processes of mutation, selection, and genetic change.       | Principles of evolution help promote an understanding of natural selection and genetic drift and their contribution to the diversity and history of life on Earth. |
| Structure and function (SF)       | Basic units of structure define the function of all living things.                                     | Structural complexity, together with the information it provides, is built upon combinations of subunits that drive increasingly diverse and dynamic physiological responses in living organisms. |
| Pathways and transformation of energy and matter (PTEM) | Biological systems grow and change by processes based upon chemical transformation pathways and are governed by the laws of thermodynamics. | An understanding of kinetics and the energy requirements of maintaining a dynamic steady state is needed to understand how living systems operate, how they maintain orderly structure and function, and how the laws of physics and chemistry underlie such processes as metabolic pathways, membrane dynamics, homeostasis, and nutrient cycling in ecosystems. |
| Information flow, exchange, and storage (IFES) | The growth and behavior of organisms are activated through the expression of genetic information in context. | From gene expression networks to endocrine mechanisms for physiological regulation, and from signal transduction and cellular homeostasis to biogeochemical cycling, all may be understood in terms of the storage, transmission, and utilization of biological information. |
| Systems (S)                       | Living systems are interconnected and interacting.                                                     | Mathematical and computational tools and theories grounded in the physical sciences enable biologists to discover patterns and construct predictive models that inform our understanding of biological processes. Through these models, researchers seek to relate the dynamic interactions of components at one level of biological organization to the functional properties that emerge at higher organizational levels. |
Appendix 2: An example 5CC matrix chart used in this study.

| Core Concept(s) | Biology level(s) | M-molecular/cellular | O-organismal | P-population/ecology |
|-----------------|------------------|----------------------|--------------|----------------------|
| (SF) Structure and Function |                   |                      |              |                      |
| (S) Systems     |                   |                      |              |                      |
| (IFES) Information Flow, Exchange, Storage |                   |                      |              |                      |
| (E) Evolution   |                   |                      |              |                      |
| (PTEM) Pathways of Transformations of Energy and Matter |                   |                      |              |                      |
Appendix 3: Qualitative analysis of students using a 5CCs matrix chart to understand PSL. Scales used include molecular (M), organismal (O), and population (P). Conceptual Elements (Cary and Branchaw, 2017) were used to frame a deductive analysis with the goal of linking student responses to the most relevant CE in each given core concept (CC). Students were requested to fill in at least three cells of the matrix table, thus the n values represent the total number of responses received per CC in each exam.

| Conceptual Element | Example student response | Scale(s) used | Example student response | Scale(s) used |
|--------------------|--------------------------|---------------|--------------------------|---------------|
| **Evolution (E)**  |                          |               |                          |               |
| E2: The phenotypes of living organisms result from the gain and loss of traits along their lineage. | “coral that already resided in warm waters show new coral adopting in 2 years and[..]” | (n=31) | “… salamanders have passed down DNA, which makes the regeneration process quicker[..]” | (n=13) |
| E4: Phenotypes, based upon underlying genotypes and environmental factors, can be subject to selective pressure. | “separate colonies adapted after 12-27 months, demonstrating acquired heat resistance.” | 47 (%) | “The protein nAG... since limbs are being lost it can cause it to reproduce faster on a cellular level[..].” | 23 (%) |
| E5: Organisms have greater fitness if they have a phenotype that increases their ability to survive and reproduce in a particular environment. | “the coral’s genes that survive the increasing temperature are able to reproduce, more favorable for such conditions[..]” | 41 (%) | “many organisms have evolved with regenerative abilities, increasing their fitness and survival rates.” | 46 (%) |
| Other | 9 irrelevant or incomplete statements | 15 irrelevant or incomplete statements | | |
| **Structure and Function (SF)** |                          |               |                          |               |
| SF1: Biological structures from the molecular to the ecosystem scale, and their interactions are determined by chemical and physical properties that both enable and constrain function. | “the amount of chlorophyll was directly proportional to the survival rates of the corals due to its energy retention function.” | (n=14) | “nAG is released and acts directly on blastemal cells to help begin regeneration.” | (n=24) |
| SF2: Individual structures can be arranged into organized units that enable more complex functions. | “reef building corals create habitats for other organisms” | 7 (%) | | |
| SF4: Structural features are dynamic and modifications can be made in response to environmental changes that are compensatory to restore lost function or noncompensatory to eliminate functions that are no longer needed. | “74 coral genes changed significantly between the two pools.” | 50 (%) | “when amputated, the severed axons are retracted which regenerate[..]” | 21 (%) |
**Information Flow, Exchange and Storage (IFES)**

| IFES1: Information exists in many forms and is relayed within and across biological molecules, cells, tissues, organisms, populations, and ecosystems. | 14 | “the information of genetic material was exchanged from the HV coral pool into the MV.” | (n=21) | “the peripheral nerves and the wounded epidermis are key tissues in letting the stem cells know that regeneration is headed the specified wounded area.” | (n=14) |
| --- | --- | --- | --- | --- | --- |
| IFES4: Information from the environment regulates protein synthesis and activity, which control cellular processes and thereby organismal and population-level activity. | 33 | “corals receive an environmental stimulus which can influence stressors[...]” | 29 | “nAG expression in blastema following amputation signals the cells of the blastema to divide and grow.” |  |
| IFES5: Organisms transmit genes and epigenetic information to their offspring. | 24 | “previously adapted coral shared evolutionary information to withstand heat through gene flow[...]” |  |  |  |
| Other | 29 | irrelevant or incomplete statements | 0 | irrelevant or incomplete statements |  |

**Pathways of Transformation of Energy and Matter (PTEM)**

| PTEM1: Energy is neither created nor destroyed, but can be transformed from one form to another to generate biological activity. | 1 | “[...]too much heat can affect chlorophyll retention and result in nutrient loss.” | (n=17) | “energy converted into a form of limb regeneration[...].” | (n=11) |
| PTEM2: Input of energy, which can be from different sources, is needed to build and maintain biological entities, thereby lowering entropy in the system. | 5 | “coral has chlorophyll that helps in the process of making ATP.” | 4 | “when a limb is lost more energy from the body such as [...] is used at that specific point to reform the limb.” |  |
| PTEM5: Biological entities regulate the synthesis, storage, and mobilization of biological compounds to meet energy demands. | 6 | “[...]high retention of chlorophyll would show a higher resistance because the coral is preserving its energy.” | 9 | “once limb is cut nAG proteins work with Rod1 cell surface proteins to start the growth of the new limb[...]” |  |
| Other | 24 | irrelevant or incomplete statements | 36 | irrelevant or incomplete statements |  |

**Systems (S)**

| S1: Biological entities interact through chemical and physical signals that can | (n=17) | “the nervous system delivers regulators such as | (n=13) |  |  |
be transient, depend on spatial organization, and are influenced by environmental factors.

| S2: Changes in one component of a biological system can affect or be regulated by other components of the same system. | 53 | “if corals die out, then the coral reef ecosystem as a whole will fail.” | 8 | “nAG plays a key role in the regenerative system in amphibians and can affect the growth factor of new blastemal cells.” |
| S3. Biological systems can be defined at different scales, interact within and across scales, and together form complex networks. | 15 | “the salamander’s nerve and endocrine system all work together following amputation to form blastemal that regenerate distal limbs.” |
| S4: Biological systems include and are affected by biotic and abiotic factors in the environment. | 29 | “heat resistance is beneficial to the survival of the coral reef ecosystems” |
| S5: Interactions between and among biological entities can generate new system properties. | 12 | “more coral reef systems will be created due to the new resistant MV coral pools.” |
| Other | 6 | irrelevant or incomplete statements | 31 | irrelevant or incomplete statements |
Appendix 4: Questionnaire items used in this study.

| Questionnaire | Subscale | Item                                                                                                                                 |
|---------------|----------|-------------------------------------------------------------------------------------------------------------------------------------|
| **Student Attitudes of Learning Gains** (Seymour et al., 2000) | **Application of knowledge to research**  | Before/After participating in this course, how likely were you to:  |
|               |          | Identify limitations of research methods and designs?  |
|               |          | Understand connections among scientific disciplines?  |
|               |          | Understand the relevance of scientific research to your coursework?  |
|               |          | Engage with real-world science research?  |
|               |          | Feel like a scientist?  |
|               |          | Think creatively about scientific research?  |
| **Student Attitudes of Learning Gains** (Seymour et al., 2000) | **Attitudes or behaviors as a researcher** | Before/After participating in this course, how likely were you to: |
|               | | Identify limitations of research methods and designs?  |
|               | | Understand connections among scientific disciplines?  |
|               | | Understand the relevance of scientific research to your coursework?  |
|               | | Engage with real-world science research?  |
|               | | Feel like a scientist?  |
|               | | Think creatively about scientific research?  |

**Motivation in reading PSL** (Chatzikyriakidou & McCartney, 2022)

- **Expectancy value in reading PSL**
  - Reading primary scientific literature is valuable to me as a student.
  - It would be useful for my future career to read primary scientific literature.
  - The amount of effort it takes to read primary scientific literature is worthwhile to me.
  - I feel that being good at reading primary scientific literature is important to me.
  - Reading primary scientific literature is useful in my daily life.

- **Self-efficacy in reading PSL**
  - I think that I can understand the experimental design from a primary scientific literature article.
  - I think that I can understand the data presented in a primary scientific literature article.
  - I think that I can understand the results section from a primary scientific literature article.
  - I think that I can understand the discussion section from a primary scientific literature article.
  - I think that I can understand the overall ideas presented in a primary scientific literature article.

- **Performance/competence in reading PSL**
  - I am confident that I can understand primary scientific literature articles I read in class.
  - I can do well on exams based on primary scientific literature I have read as a class assignment.
  - I understand concepts I have studied through reading primary scientific literature.
  - I can overcome setbacks in reading primary scientific literature.
  - Others ask me for help with reading primary scientific literature.
  - I am confident that I can understand primary scientific literature I read outside of class.

- **Interest in reading PSL**
  - I am interested in reading more primary scientific literature.
  - Topics I read about in primary scientific literature excite my curiosity.
  - I enjoy learning about primary scientific literature.

**Biology identity** (Godwin et al., 2016)

- **Performance/competence in biology**
  - I am confident that I can understand biology in class.
  - I can do well on exams in biology.
  - I understand concepts I have studied in biology.
  - I can overcome setbacks in biology.
  - Others ask me for help in biology.
  - I am confident that I can understand biology outside of class.

- **Interest in biology**
  - Topics in biology excite my curiosity.
  - I enjoy learning about biology.
  - I am interested in learning more about biology.