3-25-2019

Analysis of Questions from Undergraduate Introductory Biology Students

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Abstract

The types of questions that students ask can be indicative of their science knowledge. Students questions can reveal to instructors what students do or do not understand about the material, and what about the material they are interested in. We were interested in the types of questions students ask specifically in the context of an introductory, undergraduate biology class. Here, students were prompted to provide questions that they had about the material they were to study before lecture. Our research question was: what types of questions do students ask when preparing for class when given freedom to choose their resources? To answer this question, we used emergent thematic analysis to create a taxonomy of the types of questions students asked as a part of an assignment where students were asked how they prepared for that day's lecture, and to provide a question that they had about the topic given open resources (i.e., allowed to refer to whatever resources they wanted, not just read a textbook). We found that students ask a variety of questions. Students most frequently asked questions about simple definitions and mechanisms. Students asked about malfunctions in biological systems least often. Understanding the types of questions students ask will serve as one piece that will help instructors guide their students on how to effectively prepare for class and understand biological concepts.

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Introduction

The ability to question is an important skill in science fields and is expected as one of the many skills a scientist practices (National Research Council, 2000). From ancient to contemporary models of scientific inquiry, asking questions has been a crucial component which provides the basis for scientific experiments and explanations (Kaberman & Dori, 2008; van Mil, Boerwinkle, & Waarlo, 2011). National organizations have published documentations outlining question asking as a scientific practice that science researchers engage in (National Research Council, 2000). This is not surprising since asking questions promotes inquisitiveness and initiates the learning process (Aguiar, Mortimer, & Scott, 2009; Gautier & Solomon, 2005; Marbach-Ad & Sokolove, 2000a&b; van Mil et al., 2011; Lai & Law, 2012). This inquisitiveness is reflected from research scientists attempting to solve a problem or close a gap in research, to children who are inherently curious trying to figure out the world around them. Asking questions is a guiding step in research that scientists use to pinpoint what they want to learn.

Given that questioning is an important skill for scientists, students in science should then also practice questioning. This skill is especially important to hone at the post-secondary level as students are close to moving into research fields that require them to formulate questions intended to solve problems and fill gaps in science literature rather than simply finish an assignment. Asking questions promotes students to adopt thinking methods used by scientists that help to understand scientific concepts and also help to further develop the high-level questions used in scientific inquiry that are necessary for building scientific knowledge (Aguiar et al., 2009; Chin & Osborne, 2008; Gautier & Solomon, 2005; Hakkarainen, 2003; Harper, Etkina, & Lin, 2003; Kaberman & Dori, 2008; Lai & Law, 2012; Marbach-Ad & Sokolove, 2000b).

In addition to students practicing the same skills as scientists to foster efficient research skills, questioning has been shown to have wide-reaching benefits for students' learning of science. This includes encouraging higher-level cognitive thinking (Aguiar et al., 2009; Harper et al., 2003; Kaberman & Dori, 2008), stimulating metacognition where students reflect on their learning to help overcome knowledge-building challenges and limitations (Pittenger & Lounsbery, 2011), refining problem-solving skills (Dori & Herscovitz, 1999; Tolpannen & Aksela, 2018), enhancing overall student understanding of material (Harper et al., 2003; Marbach-Ad & Sokolove, 2000b), and increased text comprehension (Chin & Brown, 2002; Pittenger & Lounsbery, 2011). Implementing student question-asking in the classroom benefits student learning because it promotes engagement in the material and encourages them to prepare before lectures (Marbach-Ad & Sokolove, 2000a; Moravec, Aguilar-Roca, O'Dowd, 2010; Pittenger & Lounsbery, 2011). Preparing before lectures has been shown to be beneficial when learning new material (Gammerdinger & Kocher, 2018; Marrs & Novak, 2004; Moravec et al., 2010; O'Dowd & Aguilar-Roca, 2009).

Moreover, asking questions can help when learning biology specifically. The interdisciplinary nature of biology requires an understanding of different subjects (e.g., physics, chemistry) that contribute to the comprehension of different and complex biological systems and mechanisms (Dupré, 2010; Fox Keller, 2009). Questioning can help overcome the challenges that come along with attempting to piece together and make sense of biological systems and mechanisms (van Mil et al., 2011).

Despite the benefits of students asking questions during their learning process, this skill is seldom practiced in the traditional classroom setting by science students. Due to large class sizes, curriculum structures, social anxiety, or teacher-student dynamics, implementation of student question asking is difficult and students therefore may feel discouraged from asking questions and not practice this skill frequently enough to benefit from it (Watts, Gould, & Alsop, 1997). In fact, most students have stopped asking questions some time during their elementary years (Becker, 2000) and many of the questions that are brought up are superficial, procedural, and informational, as opposed to questions that could potentially generate meaningful discussion and learning (Chin & Osborne, 2008; Dillon, 1988; Harper et al., 2003).

When students questioning is practiced, it can take a number of forms, such as when students are preparing for a lab (Keeling, Polacek, & Ingram, 2009), after reading research articles (Brill & Yarden, 2003), as a homework assignment (Marbach-Ad & Sokolove, 2000b), after analysing case studies (Dori & Herscovitz, 1999), after using computer stimulations (Hakkarainen, 2003; Kaberman & Dori, 2008; Lai & Law, 2012), and after collaborative discussions (Lai & Law, 2012; Zhang et al., 2007).

It is not enough to have students just practice asking questions, but we as instructors and researchers also need to assess students' questioning abilities. Student questions can alert teachers of any misunderstandings and misconceptions (Harper et al., 2003), what topics need more attention (Harper et al., 2003), give insight into how students are learning (Mitchell, 2010), what mental models they are forming (Aguiar, Mortimer, & Scott, 2009; Chin & Osborne, 2008), and their interests (Demirdogen & Cakmacki, 2014; Pittenger & Lounsbery, 2011).

Understanding how well students are capturing the material inside and outside the classroom and what details they want to learn about can be taken into consideration by course instructors and affect the way the curriculum is taught or structured. The effects of what we learn from student questions on classroom settings can be numerous and can lead to an overall improvement in student learning of biological concepts (Marbach-Ad & Sokolove, 2000b).

While current literature has provided some insight into students' questioning skills, the benefits of students asking questions, and the pedagogical techniques to help students improve their questioning skills, more work in different contexts will continue to enhance our understanding and facilitation of this vital scientific skill. In this study, we sought to understand the types of questions students asked when preparing for class in the context of undergraduate biology. Specifically, students enrolled in a large lecture, active learning-style course were assigned to prepare for each lecture by familiarizing themselves with daily content using whatever resources they preferred (e.g., textbook reading, online videos) and report on their preparation including asking question(s) about the scientific content. We used thematic analysis (Braun and Clarke, 2006) to categorize the students' questions qualitatively (Creswell, 2012). Below we describe the processes and findings of that work and provide insight on what types of questions were asked by the students.

Methods

Study Context

The study was conducted at a large four-year, doctoral-granting university in the Midwestern United States. The course was student-centered and used active learning as a pedagogical approach. The course was an introductory cellular biology class taught in a large lecture hall that counts towards a biology major. Course content consisted of basic biological concepts including the chemistry of biology, structure and function of large biomolecules and cellular components, metabolic processes, gene expression and regulation, and inheritance. We gathered and analyzed data from 91 consenting students out of a total class population of 117 (consent rate of 78%). Student demographic data can be found in Table 1. This work was conducted with approval from the institutional review board (#HS17-0259).

Table 1. *Student Demographics*

	n
N	91
Females	63
Males	28
18-21 years	69
22-25 years	16
26-40 years	6
White/Non-Hispanic	49
Hispanic or Latino/Latina	11
Black or African American/Non-Hispanic	11
Asian	9
Multiple Ethnicities	11
Freshman	33
Sophomore	26
Junior	22
Senior	7
Graduate or Postbacc	3
First Generation	48
Transfers	24
Cum. GPA (SD)	3.0 (0.8)

Assignment

Students were expected to familiarize themselves with the topics covered in class before every lecture. They had freedom to use whatever resources they deemed appropriate to learn about concepts (e.g., reading a textbook, watching a video, reading online material). Completing this assignment counted towards their course grade (10%). The assignment was submitted online where students provided the following information: (1) what day they prepared for, (2) what resources they used to prepare, (3) what they did to prepare for the class, (4) what they learned during their preparation, (5) what questions they had regarding the material during their preparation (which we analyzed for this project), and (6) identifying information. The date and time of each survey submitted was included automatically. The full assignment is provided in Supplemental Material 1.

Analysis

We categorized student questions with several rounds of qualitative analysis (Creswell, 2012). First, we attempted to apply a published framework that was developed for student questions in an undergraduate biology laboratory course (Keeling et al., 2009). However, the framework narrowly focused on laboratory practices, procedures, and observations and therefore was not applicable to our context (i.e., large-enrollment lecture). Next, we attempted to apply another published framework that was developed for student questions from a large introductory biology course (Marbach-Ad & Sokolove, 2000b). Again, the framework was not applicable. Many of the question categories were defined based on what information was available in the assigned textbook chapters; the students in our study did not have assigned text readings. Therefore, categories such as “Questions about a simple definition, concept, or fact that could be looked up in the textbook,” and “Questions in which the student seeks more information than is available in the textbook” were not applicable to our data or context. Several attempts at combining and adapting the Keeling et al. (2009) and Marbach-Ad and Sokolove (2000b) frameworks resulted in low interrater reliability (Gwet, 2014); therefore, we changed our approach.

We analyzed student questions using emergent thematic analysis to qualitatively analyze our data (Braun & Clarke, 2006). Below we outline how we used the 6 phases of Braun and Clarke's (2006) method for thematic analysis for our study.

The first phase of thematic analysis is familiarizing ourselves with our data. The Keeling et al., (2009) and Marbach-Ad and Sokolove (2000b) frameworks resulted in low interrater reliability meaning that we had to run through the data over and over again in attempt to reach an acceptable interrater reliability. During this process, the authors inevitably became very familiar with the data. Braun and Clarke (2006) emphasized actively reading the data to identify patterns. We were able to identify patterns in our data as we realized the inapplicability of previous research frameworks.

The second phase is generating initial codes. After becoming more familiar with the data, we generated our initial codes by tweaking the available frameworks to fit the context of our study more. For example, students were not assigned any readings or a textbook in our study; therefore, category 1b of Marbach-Ad and Sokolove (2000b) "Questions about a simple definition, concept, or fact that could be looked up in the textbook" was changed to "Questions about a simple, single definition, concept, fact, or expected knowledge that could be easily and quickly looked up in a resource". We made our codes vague because the instructions for how students could obtain their information was relatively vague. Even with this revised framework, we continuously failed to reach an appropriate interrater reliability and the framework still did not fit the context or purpose of our study. Eventually, we started organizing our data into meaningful groups and patterns we noticed in the data. Braun and Clarke (2006) explain a theory-driven approach where certain patterns are noticed in the data to fit the question of our study. We were specifically looking for questions about the biological content and concepts to be lectured about, so we identified patterns that would categorize types of questions about biological content. Not every question was relevant to our study. Any questions outside of biological content were basically lumped into one of two of our final categories (i.e., “NA” or “Irrelevant”).

The third phase is searching for themes. The meaningful groups and patterns we established in the second phase were used to code some of the data where we ended up reaching a better interrater reliability. We found many questions seeking basic concepts, comparisons, further description of mechanisms, malfunctions, and examples. We kept Keeling et al.’s (2009) and Marbach-Ad and Sokolove’s (2000b) category concerning ethical concerns in student’s questions.

The fourth phase is reviewing our themes. After coding some of the submissions using the codes that we produced by noticing the patterns in our data, we condensed, separated and removed certain codes. We found that some of the themes were too similar to each other and didn’t have enough distinction so we condensed them into one category. We found others, like the category concerning ethics, was irrelevant for our study so we removed it. Questions concerning ethics were ultimately placed in either “NA” or “Irrelevant”. We eventually determined the categories to place the student questions and it was found that most, if not all, of the questions were able to be analysed by our proposed framework.

The fifth phase is defining and naming themes. We refined our framework by naming our categories and further defining them. After being able to define what kinds of questions would go into each category, we named them accordingly depending on the overall theme of the category. Our names and definitions for each category in our framework is presented in Table 2.

The sixth phase is producing a report. The final framework is presented in Table 2. All 2394 of the questions were categorized based on our finalized framework and this paper reflects how we used our taxonomy and how it applied to our context and study.

The authors co-coded 343 (14%) of the questions independently and not previously discussed and achieved an initial inter-rater reliability of 78%. Any disagreements between the two authors were discussed until a consensus was reached for 100% for the sample of questions. After which, a single author (SS) coded the rest of the sample. All names given in the results as examples are pseudonyms. If students asked more than one question, we only categorized the first question.

Table 2. *Framework for analysing student questions*

Category Name	Category Description
NA	Student did not provide a question or asks a question about the course (e.g., what's on the test?) or non-biological content.
Irrelevant	The question does not make sense grammatically or logically, is irrelevant (about scientific experiments or methods/procedure), or there is misunderstanding or misconception of the material.
Simple Definition	Seeks a basic or simple definition of a concept (answer is a single term); could include a simple function or structure of a molecule; is a close ended question; seeks absolutes (e.g. "are all…", "do all…") could be phrased as a sentence (e.g. "I want to know more about…").
Malfunction	Seeks what can cause a malfunction, if some part of a system could go wrong, or the consequences if some part or aspect of a system or process were to go wrong.
Examples	Seeks examples for concepts or examples of an exception or example of differences among organisms (but not G); sometimes to a common fact or concept.
Significance/ Purpose	Seeks explanation to why something is necessary to a system, function of a system, or biological processes as a whole; or evolutionary question (mostly "why" questions).
Mechanism	Seeks something's function at a cellular, mechanistic, and/or molecular level; asks for more detail at a cellular or mechanistic level (mostly "how" questions).

Differences Between	Seeks explanation of what differentiates two concepts/structures/functions (and not differences among organisms), seeks correctness of a comparison they made, and seeks strict, specific definitions.

Results

We present frequencies and examples of student questions for each category (Table 3). Out of the 2394 coded entries, 76% of that data was non-NA questions. Of the non-NA questions, we found that the most prevalent of the students' questions sought simple definitions (20%). For example, Hannibal asked, "What powers exocytosis?" The next prevalent of the students' questions sought a mechanism (19%). For example, Ozai asked, "How does a biological system initiate a negative or positive feedback loop, and how does it know when to terminate the cycle?" The least prevalent of the students' questions sought malfunctions (5%). For example, Pam asked, "What happens when whether actin or myosin doesn't function correctly?"

Table 3. *Category frequencies and examples ordered from most to least common*

Category Name	Frequency	Representative Student Quote
NA	571 (24%)	"Can we do less activities in class?"
Simple Definition	468 (20%)	"What types of bonds are formed by the amino acids?"
Mechanism	452 (19%)	"How does each tRNA bind to its specific amino acid and not just any amino acid?"
Significance/Purpose	245 (10%)	"Why are eukaryotic cells larger than prokaryotic cells?"
Irrelevant	194 (8%)	"How did scientists figure out the structure of DNA?"
Differences between	177 (7%)	"What exactly is the difference between homologous chromosomes and sister chromatids?"
Examples	164 (7%)	"What are some examples of things that can pass through the plasma membrane?"
Malfunction	123 (5%)	"What happens when a cell can't undergo cell division?"

Discussion

Our study showcases the types of questions undergraduate students ask about biology when given freedom to choose which resources to use when preparing for class. Student questions were diverse and offer insight into what students wanted to know. We categorized all the student submissions with the framework we created using thematic analysis (Braun & Clark, 2006). Insights into each category are discussed below. We also discuss implications for teaching and future research.

Any questions not explicitly about biological content or concepts were placed in the category of NA. Instead, many of these questions were about the exams, class structure, or how to remember content. This suggests that these students did not understand the assignment, or perhaps the students were just trying to complete the assignment rather than use the assignment as a part of learning biological concepts. This also suggests that students were unsure of what types of questions they should be asking to understand relevant material.

Questions that asked about simple biological concepts or seeking clarification were placed in the category of Simple Definitions. Students most likely prepared for the class but probably did not grasp the material to a valuable extent, which causes a superficial understanding of the material. With the second highest frequency of questions (20%), this suggests that many of the students were quickly glancing over the material without meaningfully engaging with the content.

Student questions seeking more detail to biological systems at a mechanistic and cellular level were placed in the category of Mechanism. 19% of the entries were categorized as such, suggesting that, in a significant number of entries, students were interested in knowing about the entities that comprise a system, the relationships between those entities, and their contribution to the function of a system. Students appeared to be interested in how biological components interact with each other, especially at a molecular and cellular level which may suggest they were also interested in the chemistry and physics of how macromolecules work. Many of the mechanism questions suggested that students have difficulty applying related content knowledge between disciplines. Several of these questions could be answered through a general understanding of chemistry concepts. Considering the interdisciplinary nature of biology (Dupré, 2010; Keller, 2009), students should be expected to have taken or to be taking general chemistry classes during their time as biology students. The prominence of questions in the category of Mechanism emphasizes the importance of including chemistry in the biology curriculum.

Questions about evolution or importance of a component were placed in the category of Significance/Purpose. With these questions, it seems students were attempting to understand the purpose of biological systems from an evolutionary standpoint. They were trying to understand why a component or mechanism would be needed for the functioning of a system and how their roles came to be. Perhaps students wanted a deeper understanding of how much a certain function or mechanism contributes to a system and why each component is necessary. The breadth and complexity of biological phenomena could have influenced students to ask these types of questions; they may wonder why so many components are needed for one purpose or function of a biological system. Whereas students asking questions in the Mechanism category wanted to know what comprises biological systems and how biological systems work, students asking questions in the Significance/Purpose category wanted to know why those components and component functions were needed for biological systems.

Questions asking about biology history or experiments were placed in the category of Irrelevant. Although these types of questions were applicable to the assignment, they were not what we were interested in for this study. A relatively low portion of the sample (8%) was categorized as such.

Questions asking about differences between structures or concepts were placed in the category of Differences Between. Students were probably confused about the concepts and would like to know what differentiates two concepts from one another that they find to be similar. Determining differentiating characteristics can allow for better understanding of a vast amount of material (Marzano, Pickering, & Pollock, 2001).

Questions seeking examples about biological phenomena were placed in the category of Examples. Students wanted to conceptualize biological ideas and find an application of biological phenomena to real life systems. Examples could give students a better idea of the relevance of biological phenomena.

Any questions seeking to understand what would happen if something goes wrong in a system were placed in the category of Malfunction. The lowest portion of student questions were coded this way (5%). Similarly to the Significance/Purpose category, students were probably attempting to understand the importance of a component or a component’s function in a biological system. However, students specifically wanted to assess how drastic the negative effects would be on the organism or system if something went wrong. Understanding the consequences of malfunctioning could give students a better understanding of the importance of certain components or functions of a system. Knowing what the cell or organism could not do without a certain component or function can lead to a better understanding of the roles of that component or function.

Limitations

As with any study, there are some limitations to this work. Some students provided more than one question per submission, in which case we only coded the first question. Disregarding additional questions may have led to a misrepresentation of the relative proportions of the types of questions students asked. However, given our large data set (2394 submissions over an entire semester) and only a fraction (232, 10%) included multiple questions, we are confident that our analysis accurately reflects the general proportion of the types of questions students ask in this context.

Student motivations could have impacted the type of questions they asked. Students received a participation point for simply completing the assignment regardless of the type or quality of their question(s). The grade was also a relatively small portion of the grade (10%) which may have led to low motivation and them asking questions that do not accurately reflect student's abilities. Further, the data was self-reported by the students and, therefore, we were not able to identify if students actually referenced resource material before asking questions about the content. We hypothesize that if students did not familiarize themselves with relevant resources before asking a question about the biological content they were studying, as directed in the assignment instructions, they may ask superficial types of questions that do not actually reflect areas of confusion or interest. Again, whether or not the students were motivated enough to fully engage in the assignment may have affected our ability to assess their genuine questions.

Question structure is also a problem that we encountered. We used context (the part of the survey where students told us how they prepared and what they learned from their resources) in order to understand what questions the students were trying to ask. Keeling et al. (2009) explains that some students use "why" and "how" interchangeably. This can make it difficult to categorize questions since the students' intended question may not have been reflected in the language they used in their question.

Teaching Implications

This work can help inform teaching practices in several ways. First, our expansive sample provides insight into the types of questions that can be expected from introductory biology students who are given freedom to choose resources to prepare for class. Instructors can use these findings to anticipate what their students understand and have difficulty with so that they can adjust their in-class instruction and activities accordingly. Second, our general framework provides a way for instructors to assess the types of questions their students ask even if it is in a different context than what we studied here. By assessing and therefore understanding students' questions, instructors can tailor instruction and activities to students' prior knowledge, an important step in any meaningful learning event (Mintzes, Wandersee, & Novak, 2001). Third, instructors can monitor how students' questions change and can pinpoint ways that students can improve their questioning skills. For example, an active learning environment has been shown to improve questioning skills (Chin & Osborne, 2008), especially after being exposed to a taxonomy of desirable and undesirable questions (Marbach-Ad & Sokolove, 2000b). Students participating in collaborative groups to formulate and answer each other's questions also showed improvement in questioning skills (Kaberman & Dori, 2008; Lai & Law, 2012; Marbach & Sokolove, 2000b; Zhang et al., 2007). Brill and Yarden's (2003) study suggests that exposing students to primary literature may also improve on student question quality.

If instructors are interested in their students creating good-quality questions, they can give more incentive to students for higher-quality questions. Students do not seem to provide high quality questions when not prompted to do so (Keeling et al., 2009, Marbach-Ad & Sokolove, 2000b). Certain types of assignments could improve student motivation to ask high-quality questions such as where students have to conduct their own experiments or create their own projects. The assignment could also grade questions based on quality rather than completion, which could motivate students. Students also demonstrate better questioning abilities when there is more teacher guidance and encouragement (Chin & Brown, 2002; King, 1992; Kuhlthau, Maniotes, & Caspari, 2015), when they have been exposed to clear teacher expectations (Gautier & Solomon, 2005; Marbach-Ad & Sokolove, 2000b; Pittenger & Lounsbery, 2011), or when they have been exposed to primary scientific literature where they can observe how the whole scientific process comes together (Brill & Yarden, 2003). Regular exposure to scientific practices in the classroom will familiarize students with the experience of the scientific process and encourage them to think like scientists (Barab & Hay, 2001; Brill & Yarden, 2003; Gautier & Solomon, 2005; Hakkarainen, 2003).

Future Potential Research

We collected and analyzed this data to understand what types of questions students are asking when they had to prepare for class when using the resources of their choice. In the future, we will investigate how these question types align with students' overall understanding of biological concepts. This will provide insight into student learning and how their current understanding of material relates to or influences what kinds of questions they ask.

More work is also needed to understand how different contexts affect students' questions. For example, do demographics (e.g., age, class status, gender) relate to question types? How do different types of active learning strategies influence students' ability to ask questions? How do group-generated questions compare to individual-generated questions (Lai & Law, 2012)?

Moreover, we should investigate question asking from the viewpoint of the students. Perception questions such as how students feel about asking questions, if they find that the process of questioning helped them learn the material better, or if asking questions encouraged them to explore the topic before lecture, are invaluable to understanding all angles of student question asking. This could also allow us to assess if students are engaging in metacognition when they are asked to provide questions. Additionally, we would also like to see more research on how student perceptions relate to the types of questions asked and question quality.

Conclusions

Qualitative analysis of student questions is only one step to understanding students' skills in the scientific practice of questioning. It is also an important step to help instructors guide their students when preparing for class and change their curriculums to better help students learn. Students should be encouraged to ask questions and seek a deeper understanding of the material that is being presented to them. Assessing the types of questions students have after preparing for lecture contributes to the overall betterment of the curriculum and encourages instructors to adopt practices into their classrooms that are more beneficial for students. Our data shows an interest from the students that they not only seek more clarification on biological concepts but also an in depth understanding of processes at the cellular and molecular level.

Students need to be encouraged to ask questions, especially if they are expected to work in fields of science that require good questioning abilities. It is important that this skill is honed and properly implemented in science learning and at the post-secondary level. This ultimately emphasizes the importance of further analysis of student questions as it provides us with valuable information that could potentially guide instructors on how to best set up their curriculums for optimal student learning.

Acknowledgements

Thank you, Anna Zradicka, for taking the time to help edit this paper.

References

Aguiar, O. G., Mortimer, E. F., & Scott, P. (2009). Learning from and responding to students questions: The authoritative and dialogic tension. *Journal of Research in Science Teaching*. doi:10.1002/tea.20315

Barab, S. A., & Hay, K. E. (2001). Doing science at the elbows of experts: Issues related to the science apprenticeship camp. *Journal of Research in Science Teaching, 38*(1), 70-102. doi:10.1002/1098-2736(200101)38:13.0.co;2-l

Becker, R. R. (2000). The Critical Role of Students Questions in Literacy Development. *The Educational Forum,64*(3), 261-271. doi:10.1080/00131720008984763

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101. doi:10.1191/1478088706qp063oa

Brill, G., & Yarden, A. (2003). Learning Biology through Research Papers: A Stimulus for Question-Asking by High-School Students. *Cell Biology Education*, *2*(4), 266-274. doi:10.1187/cbe.02-12-0062

Chin, C., & Brown, D. E. (2002). Student-generated questions: A meaningful aspect of learning in science. *International Journal of Science Education*, *24*(5), 521-549. doi:10.1080/09500690110095249

Chin, C., & Osborne, J. (2008). Students questions: A potential resource for teaching and learning science. *Studies in Science Education*, *44*(1), 1-39. doi:10.1080/03057260701828101

Creswell, J. W. (2008). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Upper Saddle, NJ: Pearson Education International.

Demirdogen, B., & Cakmakci, G. (2014). Investigating students interest in chemistry through self-generated questions. *Chem. Educ. Res. Pract.*, *15*(2), 192-206. doi:10.1039/c4rp00037d

Dillon, J. T. (1988). The remedial status of student questioning. *Journal of Curriculum Studies*, *20*(3), 197-210. doi:10.1080/0022027880200301

Dori, Y. J., & Herscovitz, O. (1999). Question-posing capability as an alternative evaluation method: Analysis of an environmental case study. *Journal of Research in Science Teaching*, *36*(4), 411-430. doi:10.1002/(sici)1098-2736(199904)36:43.0.co;2-e

Dupré, J. (2010). It is not Possible to Reduce Biological Explanations to Explanations in Chemistry and/or Physics1 (F. J. Ayala & R. Arp, Eds.). *Contemporary Debates in Philosophy of Biology*, 32-49. doi:10.1093/acprof:oso/9780199691982.003.0009

Gammerdinger, W. J., & Kocher, T. D. (2018). Understanding Student Perceptions and Practices for Pre-Lecture Content Reading in the Genetics Classroom †. *Journal of Microbiology & Biology Education, 19*(2). doi:10.1128/jmbe.v19i2.1371

Gautier, C., & Solomon, R. (2005). A Preliminary Study of Students Asking Quantitative Scientific Questions for Inquiry-Based Climate Model Experiments. *Journal of Geoscience Education, 53*(4), 432-443. doi:10.5408/1089-9995-53.4.432

Grimberg, B. I., & Hand, B. (2009). Cognitive Pathways: Analysis of students written texts for science understanding. *International Journal of Science Education, 31*(4), 503-521. doi:10.1080/09500690701704805

Gwet, K. L. (2014). *Handbook of inter-rater reliability the definitive guide to measuring the extent of agreement among raters*. Gaithersburg, Md: Advanced Analytics, LLC.

Hakkarainen, K. (2003). Progressive inquiry in a computer-supported biology class. *Journal of Research in Science Teaching, 40*(10), 1072-1088. doi:10.1002/tea.10121

Harper, K. A., Etkina, E., & Lin, Y. (2003). Encouraging and analyzing student questions in a large physics course: Meaningful patterns for instructors. *Journal of Research in Science Teaching,40*(8), 776-791. doi:10.1002/tea.10111

Kaberman, Z., & Dori, Y. J. (2008). Question Posing, Inquiry, and Modeling Skills of Chemistry Students in the Case-Based Computerized Laboratory Environment. *International Journal of Science and Mathematics Education, 7*(3), 597-625. doi:10.1007/s10763-007-9118-3

Keeling, E. L., Polacek, K. M., & Ingram, E. L. (2009). A Statistical Analysis of Student Questions in a Cell Biology Laboratory. *CBE—Life Sciences Education, 8*(2), 131-139. doi:10.1187/cbe.08-09-0054

Keller, E. F. (2009). It Is Possible to Reduce Biological Explanations to Explanations in Chemistry and/or Physics. *Contemporary Debates in Philosophy of Biology*, 19-31. doi:10.1002/9781444314922.ch1

King, A. (1992). Facilitating Elaborative Learning Through Guided Student-Generated Questioning. *Educational Psychologist, 27*(1), 111-126. doi:10.1207/s15326985ep2701_8

Kuhlthau, C. C., Maniotes, L. K., & Caspari, A. K. (2015). *Guided inquiry: Learning in the 21st century*. Santa Barbara: Libraries unlimited.

Lai, M., & Law, N. (2012). Questioning and the quality of knowledge constructed in a CSCL context: A study on two grade-levels of students. *Instructional Science, 41*(3), 597-620. doi:10.1007/s11251-012-9246-1

Marbach-Ad G., Sokolove P. G. (2000a). Good science begins with good questions: answering the need for high-level questions in science. *J. Coll. Sci. Teach, 30*:192–195.

Marbach-Ad, G., & Sokolove, P. G. (2000b). Can undergraduate biology students learn to ask higher level questions? *Journal of Research in Science Teaching, 37*(8), 854-870. doi:10.1002/1098-2736(200010)37:83.0.co;2-5

Marrs, K. A., & Novak, G. (2004). Just-in-Time Teaching in Biology: Creating an Active Learner Classroom Using the Internet. *Cell Biology Education, 3*(1), 49-61. doi:10.1187/cbe.03-11-0022

Marzano, R. J., Pickering, D. J., & Pollock, J. E. (2001). *Classroom instruction that works: Research-based strategies for increasing student achievement.* Alexandria, VA: Association for Supervision and Curriculum Development.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (2001). Assessing understanding in biology. Journal of Biological Education, 35(3), 118–124. https://doi.org/10.1080/00219266.2001.9655759

Mitchell, I. (2010). The Relationship Between Teacher Behaviours and Student Talk in Promoting Quality Learning in Science Classrooms. *Research in Science Education, 40*(2), 171-186. doi:10.1007/s11165-008-9106-9

Moravec, M., Williams, A., Aguilar-Roca, N., & Odowd, D. K. (2010). Learn before Lecture: A Strategy That Improves Learning Outcomes in a Large Introductory Biology Class. *CBE—Life Sciences Education, 9*(4), 473-481. doi:10.1187/cbe.10-04-0063

National Research Council. (2000). *Inquiry and the national science education standards.* Washington, DC: National Academy Press.

O'Dowd, D. K., & Aguilar-Roca, N. (2009). Garage Demos: Using Physical Models to Illustrate Dynamic Aspects of Microscopic Biological Processes. *CBE—Life Sciences Education, 8*(2), 118-122. doi:10.1187/cbe.09-01-0001

Pittenger, A. L., & Lounsbery, J. L. (2011). Student-Generated Questions to Assess Learning in an Online Orientation to Pharmacy Course. *American Journal of Pharmaceutical Education, 75*(5), 94. doi:10.5688/ajpe75594

Tolppanen, S. & Aksela, M. (2018). Identifying and addressing students' questions on climate change. *The Journal of Environmental Education*, 49:5, 375-389, doi: 10.1080/00958964.2017.1417816

Van Mil, M. H., Boerwinkel, D. J., & Waarlo, A. J. (2011). Modelling Molecular Mechanisms: A Framework of Scientific Reasoning to Construct Molecular-Level Explanations for

Cellular Behaviour. *Science & Education*, *22*(1), 93-118. doi:10.1007/s11191-011-9379-7

Watts, D. M., Gould, G., & Alsop, S. (1997). Questions of Understanding: Categorizing Pupils' Questions in Science. *The School Science Review 79(286)*.

Zhang, J., Scardamalia, M., Lamon, M., Messina, R., & Reeve, R. (2007). Socio-cognitive dynamics of knowledge building in the work of 9- and 10-year-olds. *Educational Technology Research and Development*, *55*(2), 117-145. doi:10.1007/s11423-006-9019-0

Supplemental Materials 1. Assignment

Assignment. Class Preparation

Assignment. You are required to familiarize yourself with the topic that will be covered in class, for every class. Research has shown that when students prepare for class, they learn more during class (Marrs and Novak, 2004). You can familiarize yourself in a variety of ways. For example, you may read the relevant sections in the textbook, or watch an online lecture or animation, or conduct virtual experiments with tools available online.

Learning Goals. By familiarizing yourself with the content that we will covered in class, you will be prepared to develop deeper understanding of the content during class.

Learning Objectives. Upon achievement the above learning goal, you will be able to

1. Identify useful resources for learning biology.
2. Engage in class discussions about the relevant topics.
3. Monitor your understanding of biology.

Instructions. Access the link provided in Blackboard to answer the following questions about your class preparation:

1. What day of class did you prepare for?
2. What resource(s) did you use? (e.g., textbook chapter on the properties of life). If you used an online resource, include a link.
3. What did you do to prepare for class? (e.g., read, watch a video, engaged in an activity, other)
4. What did you learn during the preparation? (This should be a short, summary explanation, like a tweet. No more than 100 words)
5. What questions do you have regarding the materials covered in this preparation?
6. Identifying information so I know who is submitting the work.

The assignment must be submitted before 11:59 p.m. the night before each class. That gives the instructor and learning assistants time to identify common questions to address during class.

Evaluation: Each assignment is work 1 point and will count toward your grade. Besides this assignment, you can earn 1 point of in-class participation by answering questions in class. Together, these will make up your participation grade where you can earn a maximum of 50 points. There will be more than 50 opportunities to earn participation points. This allows you to miss a few assignments when life is busy.

Example Content Resources

Read the textbook: Campbell Biology. (editions 8 – 11 are all relevant) 2011/7ish by Reece, J. B., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Jackson, R. B. Pearson Education, Inc.

Read the PowerPoint slides by the authors of the textbook:
http://www.course-notes.org/biology/slides/campbells_biology_8th_edition

Watch video lectures on YouTube. E.g., "Campbell Biology 10th Edition" – AP Biology Chapter X Science with Mr J: https://www.youtube.com/playlist?list=PLzImZK5NhmGt1I8hQJK6JYaPKXGdHi2D3

Watch videos and take practices questions on an open-access website companion to the textbook:
http://wps.aw.com/bc_campbell_biology_10_oa/244/62507/16002033.cw/index.html

Tentative Schedule of Topics Each Class Spring 2018

Day	WK	DATES	TOPICS	DUE
0	1	M 1/15	Martin Luther King, Jr Day	No class
1		W 1/17	Introductions, Course format, Teams	Attendance
2		F 1/19	1. Properties of life 2. Themes of Biology: A. Organization i. Levels ii. Emergent properties iii. Structure/function	Class prep
3	2	M 1/22	1. Themes of biology cont'd A. Information B. Energy and matter C. Interactions D. Evolution: Natural selection	Class prep Team Project 1. Contracts
4		W 1/24	1. Scientific inquiry 2. Scientific explanations 3. Scientific language 4. Chemistry as a basis of life	Class prep
5		F 1/26	1. Chemistry and Life A. Atoms, elements, compounds, molecules B. Atoms i. Protons ii. Electrons a. Energy b. Valence c. Orbitals b. Chemical bonds i. Covalent a. Electronegativity b. Polarity ii. Ionic c. Interactions: hydrogen "bonds" 2. Water and life a. Evidence of importance	Class prep

			b. Emergent properties c. Molecular structure	
6	3	M 1/29	1. Organic Chemistry 2. Carbon 3. Representations of biomolecules 4. Isomers 5. Chemical/functional groups	Class prep
7		W 1/31	1. ATP 2. Large biomolecules A. Macromolecules i. Forming and breaking a. Enzymes b. Dehydrations c. hydrolysis ii. Carbohydrates 1. Monosaccharides 2. Disaccharides 3. Polysaccharides B. Lipids i. Fats ii. Phospholipids iii. Steroids	Class prep Team Project 2. Properties of Water Art
8		F 2/2	1. Large Biomolecules cont'd A. Proteins i. Functions ii. Structure 1. Amino acids 2. Peptide bonds 3. 4 levels 4. Influences 5. Determining stx B. Nucleic Acids i. Structure 1. Nucleotides a. Nitrogenous bases b. Pentose sugars c. Phosphate groups 2. Phosphodiester bonds	Class prep

			3. Polymers ii. Examples 1. DNA 2. RNA iii. Functions	
9	4	M 2/5	Exam 1 and discussion	
9	**4**	**M 2/5**	**Exam 1 and discussion**	
10		W 2/7	2. Large Biomolecules cont'd A. Proteins i. Functions ii. Structure 1. Amino acids 2. Peptide bonds 3. 4 levels 4. Influences 5. Determining stx B. Nucleic Acids i. Structure 1. Nucleotides a. Nitrogenous bases b. Pentose sugars c. Phosphate groups 2. Phosphodiester bonds	Class prep
11		F 2/9	Snow day- NIU campus closed- no class	Class prep
12	5	M 2/12	A. Nucleic Acids 3. Polymers ii. Examples 1. DNA 2. RNA iii. Functions C. Using learning objectives to study	Class prep
13		W 2/14	**The cell**: 1. Fundamental unit of life 2. Microscopy 3. Relative sizes of components of life 4. Major types of cells a. Prokaryotic cells b. Eukaryotic cells	Class prep

			i. Animal cells ii. Plant cells iii. Fungal cells i. Unicellular organisms 2. Assign team project 3. 3D cell model	
14		F 2/16	1. Plasma membrane 2. Nucleus a. Nuclear membrane b. Nuclear pore and pore complex c. Nuclear Lamina d. Nucleolus 3. Ribosomes 4. If time, start working on team project 3.	Class prep
15	6	M 2/19	1. Endomembrane system a. Endoplasmic reticulum (ER) i. Smooth ER ii. Rough ER b. Transport vesicles c. Golgi apparatus i. Cis face ii. Trans face d. Lysosomes i. Phagocytosis ii. Autophagy e. Vacuoles i. Food vacuoles ii. Contractive vacuoles 1. Central vacuoles	Class prep
16		W 2/21	1. Mitochondria 2. Chloroplasts 3. Peroxisomes 4. Cytoskeleton a. Microtubules b. Microfilaments (actin) c. Intermediate filaments (keratin) 5. Extracellular components a. Cell wall b. Extracellular matrix	Class prep Team Project 3. 3D cell model

			c. Cell junctions i. Plasmodesmata ii. Tight junctions iii. Desmosomes d. Gap junctions	
17		F 2/23	Finish notes on the cell	Class prep
18	**7**	**M 2/26**	**Exam 2. The cell**	
19		W 2/28	**Membranes:** 1. Structure a. Lipids i. Phospholipids 1. Saturated 2. Unsaturated ii. Cholesterol 2. Emergent properties a. Fluidity i. Evolutionary adaptation ii. Impacts on fluidity 1. Temperature 3. Membrane structure a. Proteins i. Peripheral ii. Integral iii. General Functions b. Carbohydrates i. Cell-to-cell communication ii. Glycolipids iii. Glycoproteins	Class prep
20		F 3/2	1. Membrane synthesis 2. Emergent Properties a. Selective permeability i. Passive transport 1. Without proteins a. Concentration gradients	Class prep

			b. Diffusion c. Osmosis i. Cells w/o cell walls ii. Cells w/ cell walls 2. With proteins = facilitated diffusion a. Transport proteins i. Channel prts ii. Carrier prts	
21	8	M 3/5	1. Active transport a. ATP hydrolysis b. Sodium Potassium Pump c. Membrane potential d. Electrochemical gradients e. Electrogenic pumps i. Proton pump f. Cotransport 2. Exocytosis 3. Endocytosis a. Phagocytosis b. Pinocytosis c. Receptor-mediated endocytosis	Class prep
22		W 3/7	**Unit 3- Metabolism** Intro to metabolism 1. Metabolism 2. Metabolic pathways a. Catabolic b. Anabolic 3. Energy a. Types: thermal, potential, kinetic, chemical b. Thermodynamics i. 1st law: conservation ii. 2nd law: inefficiency c. Free-energy change, ΔG d. Exergonic/ Endergonic reactions	Class prep

		e. Equilibrium 4. ATP a. ATP hydrolysis b. Drive chemical, transport, mechanical work c. ATP regeneration 5. Enzymes a. Activation energy b. Substrate specificity c. Cofactors d. Regulation i. Regulation of gene expression ii. Inhibitors 1. Competitive 2. Non-competitive iii. Allosteric regulation 1. Activation a. Cooperation 2. Inactivation iv. Feedback v. Localization	
23	F 3/9	**Cellular Respiration** 1. Catabolic pathways a. Aerobic respiration b. Anaerobic respiration c. Fermentation 2. Redox reactions a. NAD/NADH cycling 3. Organic fuels a. Carbohydrates b. Proteins c. fats 4. Phosphorylation a. Substrate-level b. Oxidative 5. Glycolysis a. Investment phase b. Payoff phase	Class prep

			6. Mitochondrial structure 7. Pyruvate oxidation/processing	
	9	M 3/12-F 3/16	Spring Break – No Classes	
24	10	M 3/19	**Cellular Respiration cont'd** 1. Start Team Project 4. Cellular Respiration Simulations 2. Citric acid cycle 3. Oxidative phosphorylation a. Electron Transport Chain b. Chemiosmosis i. Proton motive force ii. ATP synthase 4. Organic fuels 5. Tracing energy 6. Tracing carbon 7. Fermentation a. Alcohol fermentation b. Lactic acid fermentation 8. Regulation of cellular respiration	Class prep
25		W 3/21	Photosynthesis 1. Ecological context a. Photoautotrophs/Producers 2. Leaf structure a. Stomata b. Mesophyll cell i. Chloroplasts 1. Stroma 2. Thylakoids a. Membrane b. Space 3. Redox reactions 4. Stages of photosynthesis a. Light reactions i. Sunlight and wavelength ii. Light receptors iii. Pigments	Class prep

			1. Chlorophylls 2. Carotenoids 3. Excitation iv. Photosystems v. Types of light reactions 1. Linear electron flow 2. Cyclic electron flow vi. Chemiosmosis b. Calvin cycle	
26		F 3/23	1. Photosynthesis cont'd A. Calvin cycle a. Carbon fixation i. rubisco b. Reduction i. NADPH ii. Glyceraldehyde-3-phosphate (G3P) c. Regeneration of CO_2 acceptor B. C_4 pathway C. CAM pathway 2. Photosynthesis vs. cellular respiration	Class prep Team Project 4. Cellular Respiration Simulations
27	**11**	**M 3/26**	**Exam 3**	
28		W 3/28	**Cell Cycle** (second half of Campbell Chapter 12) 1. Interphase a. G1 b. S c. G2 d. G0 2. Mitotic phase a. Mitosis b. Cytokinesis 3. Checkpoints a. G1 checkpoint b. G0 c. G2 checkpoint d. M checkpoint e. Chemical signals	Class prep

			i. Cyclins ii. CDKs 1. Kinases iii. Growth factors 4. Cancer and tumors 5. Team Project 5. Cell Cycle Simulations	
29		F 3/30	**Central Dogma** DNA inquiry and structure (Ch. 16) 1. DNA as genetic material a. Vs protein b. Frederick Griffith, 1920 c. Avery, McCarty, MacLeod d. Hershey and Chase, 1952 e. Chargaff, 1950 2. DNA structure a. Rosalind Franklin b. Watson and Crick c. Double helix i. Backbone ii. Nitrogenous base pairing 1. Purines 2. Pyrimidines iii. Antiparallel 1. Nucleotide 2. Phosphodiester bond	Class prep
30	12	M 4/2	1. DNA replication a. Semiconservative model b. Origin of replication c. Replication bubble d. Replication Fork e. Helicase f. Topoisomerase g. Single-stranded binding proteins h. Primase i. RNA primer j. DNA polymerase I and III k. deoxynucleotide triphosphates (dNTPs) l. 5’→3’ elongation	Class prep

		i. Leading strand ii. Lagging strand iii. Okazaki fragments iv. DNA ligase	
31	W 4/4	1. DNA replication complex 2. DNA proofing and repairing a. Nucleotide excision and repair 3. Gene expression (Ch. 17) a. DNA b. Proteins c. RNA i. Nucleotide structure ii. nitrogenous bases: ACGU iii. Uracil iv. Phosphodiester bonds v. Polymer **d.** Transcription **i.** RNA polymerase	Class prep Team Project 5. Cell Cycle
32	F 4/6	1. Transcription cont'd a. Initiation i. Transcription factors ii. RNA polymerase b. Elongation i. 5'→3' c. Termination 2. RNA processing a. Pre-mRNA b. 5' cap c. Poly-A tail d. Introns e. Exons f. RNA splicing g. Spliceosome 3. Gene expression: Translation a. Ribosomal structure i. Ribosomal RNA (rRNA) ii. Small subunit iii. Large subunit	Class prep

			iv. Sites 1. E site 2. P site 3. A site b. Transfer RNA (tRNA) structure i. Anticodon ii. Amino acid attachment site c. Phases i. Initiation 1. Start codon (AUG) ii. Elongation iii. Termination 1. Release factor 4. Protein folding 5. Post-translational modifications	
33	13	M 4/9	Gene expression worksheet	Class prep
34		W 4/11	Regulation of gene expression (Ch. 18) Start Team Project 6. Trp operon simulation	Class prep Bring computer!
35		F 4/13	Finish Team Project 6. Trp operon simulation (due at the end of class) Review for Exam 4	Class prep Team Project 6. Trp operon simulation
36	14	M 4/16	**Exam 4**	36
37		**W 4/18**	**1. Chromosome structure (Section 16.3)** **a. Prokaryotic chromosomes** **b. Eukaryotic chromosomes** **i. Chromatin packing** **1. Histones** **2. Nucleosome** **3. 10 nm fiber** **4. 30 nm fiber** **5. 300 nm fiber**	**Class prep**
38		F 4/20	1. Chromosomal structure continued: Eukaryotic	Class prep

			i. Sister chromatids ii. Centromere iii. Homologous chromosomes 2. Cell cycle: Cell division a. Mitosis (first half of Chapter 12) i. Microtubules ii. Prophase iii. Prometaphase 1. kinetochore iv. Metaphase v. Anaphase vi. Telophase b. Cytokinesis i. Animal 1. Cleavage furrow 2. Actin/myosin ii. Plant 1. Cell plate c. Binary Fission	
39	15	M 4/23	Sexual life cycle & Meiosis (Ch. 13) 1. Heredity 2. Variation 3. Genetics a. Genes b. Reproduction i. Asexual reproduction ii. Sexual reproduction 1. Somatic cells (diploid) 2. Gametes (haploid) 3. Sexual life cycles a. Fertilization i. zygote b. Meiosis	Class prep
40		W 4/25	1. Meiosis a. cell cycle b. G1 phase c. S phase d. G2 phase	Class prep **Team Project 7. Rate teammates**

			2. Meiosis I a. Prophase I i. Tetrad ii. Crossing over b. Metaphase I c. Anaphase I d. Telophase I and cytokinesis 3. Meiosis II a. Prophase II b. Metaphase II c. Anaphase II d. Telophase II and cytokinesis 4. Genetic diversity 5. Fertilization	
41		F 4/27	1. Mendelian Inheritance (Ch. 14) a. Mendel's pea experiments i. P, F1, F2 generations ii. Alleles iii. Dominant/recessive iv. Law of segregation v. Independent assortment b. Punnett Square c. Homozygote d. Heterozygote e. Genotype f. Phenotype g. Probability laws h. Disorders i. Recessively inherited 1. Albinism 2. Cystic fibrosis 3. Sickle-cell disease ii. Dominantly inherited 1. Dwarfism 2. Huntington's	Class prep
42	16	M 4/30	1. Non-Mendelian Inheritance a. Single gene i. Incomplete dominance	Class pre

			ii. Codominance iii. Multiple alleles iv. Pleiotropy b. Multiple gene i. Epistasis ii. Polygenic inheritance	
43		W 5/2	1. Inheritance: chromosomal (sections of Ch. 15) a. Chromosomal basis of sex i. Sex determination ii. Sex and gender iii. Sex-linked genes b. Genomic imprinting and epigenetics c. Organelle genes 2. Review	Class prep
44	**17**	**Wed. 5/9 10-11:50 a.m.**	**Exam 5 and Cumulative Final**	