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# Undergraduate Students Develop Questioning, Creativity, and Collaboration Skills by Using the Question Formulation Technique

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# Undergraduate Students Develop Questioning, Creativity, and Collaboration Skills by Using the Question Formulation Technique


**Abstract**

Asking questions can be one of the most difficult, yet important, steps in driving student inquiry. As post-secondary instructors work to integrate inquiry into classrooms, very few concrete strategies exist for developing and promoting student questioning. The Question Formulation Technique (QFT) is a structured process used widely in K-12 settings that guides students through generating, evaluating, and reflecting on questions. In these contexts, the QFT has been shown to develop important skills, including building creative capacity (divergent and convergent thinking), metacognition, and collaborative teamwork. While we have used QFT in many contexts with undergraduate students, there is very limited evidence of effectiveness and impact beyond K-12. In this study, we explored how students collaboratively developed questions using the Question Formulation Technique (QFT) in an undergraduate upper-division biology class. We documented and explored themes in question generation and collected student group reflections on their experiences. We show that undergraduate students are productive in generating questions using QFT, and asking questions broadly across the course themes, with the number of questions increasing by the end of the term. Students enjoyed the QFT process, were excited by the questions generated, and found the collaborative brainstorming effective. We also reflect on our experiences and provide ideas for other ways QFT can be incorporated into courses to support undergraduate inquiry and research. We found that QFT helps biology undergraduate students ask their own questions and use inquiry to explore concepts creatively and collaboratively.

Savoir poser des questions peut s’avérer être l'une des étapes les plus difficiles, mais aussi l'une des plus importantes, de la quête d’information des étudiants et des étudiantes. Alors que les enseignants et les enseignantes de l'enseignement supérieur s'efforcent d'intégrer la recherche dans les salles de classe, il existe très peu de stratégies concrètes pour développer et promouvoir le questionnement chez les étudiants et les étudiantes. La technique de formulation de questions (TFQ) est un processus structuré largement utilisé dans les établissements d'enseignement primaire et secondaire, qui guide les élèves dans la formulation, l'évaluation et la réflexion sur les questions. Dans ces contextes, il a été démontré que la TFQ permettait de développer des compétences importantes, notamment de renforcer la capacité créative (pensée divergente et convergente), la métacognition et le travail d'équipe collaboratif. Bien que nous ayons utilisé la TFQ dans de nombreux contextes avec des étudiants et des étudiantes de premier cycle, il existe très peu de preuves de son efficacité et de son impact au-delà de l’école primaire et du secondaire. Dans cette étude, nous avons exploré la façon dont les étudiants et les étudiantes ont développé des questions en collaboration en utilisant la technique de formulation de questions (TFQ) dans un cours de biologie de premier cycle. Nous avons documenté et exploré les thèmes de la génération de questions et recueilli les réflexions des groupes d'étudiants et d’étudiantes sur leurs expériences. Nous montrons que les étudiants et les étudiantes de premier cycle sont productifs lorsqu'ils génèrent des questions à l'aide de la technique de formulation de questions, et qu'ils posent des questions sur l'ensemble des thèmes du cours, le nombre de questions augmentant au fur et à mesure de la progression du trimestre. Les étudiants et les étudiantes ont apprécié le processus de TFQ, ont été enthousiasmés par les questions générées et ont trouvé le processus collaboratif de TFQ très efficace. Nous réfléchissons également à nos expériences et proposons des idées pour intégrer la TFQ dans les cours afin de soutenir la quête d’information et la recherche des étudiants et des étudiantes de premier cycle. Nous avons constaté que la TFQ aidait les étudiants et les étudiantes en biologie à poser leurs propres questions et à utiliser la recherche pour explorer les concepts de manière créative et collaborative.

**Keywords**
questioning, question generation, creativity, collaboration, Question Formulation Technique, QFT, biology, undergraduate education, zoology, invertebrate, evolution, structure function, ecology, applications; questionnement, génération de questions, créativité, collaboration, technique de formulation de questions, TFQ, biologie, enseignement de premier cycle, zoologie, invertébrés, évolution, structure, fonction, écologie, applications

**Cover Page Footnote**
The University of Calgary, located in the heart of Southern Alberta, both acknowledges and pays tribute to the traditional territories of the peoples of Treaty 7, which include the Blackfoot Confederacy (comprised of the Siksika, the Piikani, and the Kainai First Nations), the Tsuut'ina First Nation, and the Stoney Nakoda (including Chiniki, Bearspaw, and Goodstoney First Nations). The City of Calgary is also home to the Métis Nation of Alberta Region 3. The University of Calgary is situated on land Northwest of where the Bow River meets the Elbow River, a site traditionally known as Moh'kins'tsis to the Blackfoot, Wîchîspa to the Stoney Nakoda, and Guts'ists'i to the Tsuut'ina. On this land and in this place we strive to learn together, walk together, and grow together "in a good way."

We would like to acknowledge and thank the students who participated in the Question Formulation Technique exercises in the winter 2020, particularly their enthusiasm and effort during a time of emergency remote learning. This project was conceptualized and discussed as part of a "Creativity in Science" Community of Practice, and we would like to thank the members of this group – Jennifer Adams, Jennifer Cutherbertson, Farideh Jalilehvand, Robert Kelly, Vivian Mozol, and Kristal Turner - for their thoughtful ideas and recommendations on our work. We would also like to acknowledge the contributions of undergraduate researchers Aliza Weden and Claire Paton for their time spent discussing and providing feedback on our questions, study design, and analysis. Undergraduate researchers (co-authors JF, CJHH, SK) were funded through a University of Calgary Teaching & Learning Grant–Advancing creativity in post-secondary STEM contexts. This research was reviewed by our university's Research Ethics Board, REB16-2430 (Student learning in zoology).

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Student-generated questions can engage student curiosity and drive discovery in undergraduate courses and research experiences. As instructors answer calls to integrate student inquiry in undergraduate courses (American Association for the Advancement of Science [AAAS], 2011; Booth, 2006; Boyer, 1998; National Research Council Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century [NRCC], 2003), there is a clear need to develop undergraduate students' skills in generating questions. Generating and framing questions is a key transferable skill important for many careers (e.g., Butz & Branchaw, 2020; Clemmons et al., 2020; Willison & O'Regan, 2007). As a foundational part of the inquiry process of science, questions can also bring the joy and creative spirit of science in a range of science settings (Rothstein & Santana, 2011; Vale, 2013). Likewise, providing students with the opportunity and skills to develop questions can transition inquiry from instructor-led to student-driven and provide opportunities for creative development (Chin & Osborne, 2008; Herranen & Aksela, 2019; Strassmann, 2020; Ulibarri et al., 2019). However, surveys of university instructors have found that skills important to asking questions—creativity, critical thinking, research framing, and reflection—are among the most difficult skills to teach students (Walkington et al., 2011).

Incorporating student questioning into undergraduate coursework and learning activities can reveal student thinking and enhance student learning. For example, students in an active-learning biology class who received training in generating a question and categorizing types of questions, developed more thoughtful and higher-level questions than students in a lecture-based course (Marbach-Ad & Sokolove, 2000). Likewise, education students trained in question-generation and metacognition who engaged in self- or collaborative- questioning showed higher comprehension of lecture material than students who reviewed material on their own or in a group (King, 1989). Interestingly, researchers have found improved learning benefits based on the number of questions or depth/content of questions. In an undergraduate psychology course, the number of questions (regardless of content depth) correlated with improved test scores (Berry & Chew, 2008). In contrast, conceptual depth of questions (and not the number of questions) resulted in higher scores on a concept inventory in physics (Harper et al., 2003).

Undergraduate students can develop question-generation skills through mentorship and targeted coursework and activities in a range of settings (e.g., Badia, 2016; King, 1989; Marbach-Ad & Sokolove, 2000; Rothstein & Santana, 2011; Pott & Nortjé, 2021; Dorland, 2022). Instructional resources to train students in scientific questioning tend to focus on two important steps of the process: question generation and research framing. The Question Formulation Technique (QFT) is a scaffolded process to generate questions developed and used in various settings, from kindergarten to professionals (Rothstein & Santana, 2011). The QFT includes five core components, where divergent thinking, convergent thinking, and metacognition/reflection skills are practiced (Rothstein & Santana, 2011). Students are first presented with a question focus—an image, statement, video, or other prompt. Students then ask as many questions as possible while following a set of rules: do not stop to discuss, judge, or answer any question; record questions exactly how they are stated; and change statements into questions. Next, students work to improve their questions by identifying and changing questions from closed (can be answered in 1-3 words) to open-ended (requires a longer response). Finally, students prioritize their questions, develop an action plan, and share their questions. To develop metacognition, students reflect on their experiences during each step of the process. Students engage in the QFT in groups, which further allows the development of collaboration and teamwork skills.

To promote student questioning, we have used the Question Formulation Technique with undergraduates in a wide range of settings—lecture-based activities, course-based research experiences, community-engaged learning, international collaborations, independent and group research projects, field research, and professional development. While there is evidence of the effectiveness of QFT in K-12 (e.g., Mannion, 2019; Minigan et al., 2017; Minigan & Beer, 2017; Rothstein et al., 2015), and many examples and resources for K-12 use (Right Question Institute, 2023), there is limited evidence of its use and effectiveness in post-secondary education. QFT in post-secondary settings has been most studied in engineering (LeBlanc et al., 2017; Dera et al., 2020; Torres Garibay et al., 2020; Al-Olimat 2022), and there is a recognized need for further exploration of QFT in different disciplines (Scharf & Dera, 2021). In this study, we explored the process of students' developing questions through the QFT in an undergraduate upper-division biology class. We documented and explored themes in question generation and collected student group reflections on their experience. We show that undergraduate students are productive in generating questions using QFT, and asking questions across all the course themes. Additionally, the number of questions increased by the end of the term. Our qualitative, reflective findings show that undergraduate students enjoyed the QFT process, were excited by the questions generated, and found the collaborative brainstorming effective. We also reflect on our experiences and provide ideas for how QFT can be incorporated into courses to support undergraduate inquiry and research.

## Method

### Course Context – Invertebrate Biology

We conducted this research in a single course, Invertebrate Zoology, in the winter semester of 2020 at a research-intensive Canadian university. This research took place on the traditional territories of the people of Treaty 7, which include the Blackfoot Confederacy (comprised of the Siksika, the Piikani, and the Kainai First Nations), the Tsuut'ina First Nation, and the Stoney Nakoda (including Chiniki, Bearspaw, and Goodstoney First Nations). The City of Calgary is also home to the Métis Nation of Alberta Region 3. The research was designed and implemented in collaboration with three undergraduate researchers (co-authors JF, CJHH, SK) in commitment to a students-as-partners approach to research and teaching. This research was reviewed by our university's Research Ethics Board, REB16-2430 (Student learning in zoology).

Invertebrate Zoology is a 12-week, upper-level course aimed to introduce students to the natural history and diversity of invertebrates, which include sponges, corals, jellyfish, snails, octopus, insects, crustaceans, sea stars, and various worms. The course emphasizes how free-living and parasitic invertebrates feed, move, reproduce, and survive in marine, freshwater, and terrestrial habitats and is structured around four course themes: ecology, evolution, structure & function, and applications (e.g., research models, medicine, technology, engineering, biology-inspired design, and conservation biology). The prerequisites for this course include two introductory first-year biology courses and a second-year organismal biology (plants and animals) course. In this course, students attend three 50-minute lectures and a three-hour lab each week. In 2020, there were 120 students enrolled, with a range of students in the second to fourth+ year of their program. Students were placed into permanent teams of five to six students, for a total of 20 teams. Halfway through March 2020, the course transitioned to emergency, remote, online learning.

## Question Formulation Technique (QFT)—Application in this Course

Students completed two QFT activities in their teams during the semester; one in the first week of term and the other in the final week (week 12). At the start of the term, students completed the QFT *in person*. They were given a prompt related to one of the first four phyla that would be covered in the lecture and lab (Porifera, Cnidaria, Platyhelminthes, or Annelida). Due to the transition to remote instruction, students completed the end-of-term QFT *online* with their teams. In the second QFT activity, every team received a unique prompt on an invertebrate phylum they had previously not focused on during the term (e.g., Bryozoa, Brachiopoda). A breakdown of the QFT steps, skills practiced, deliverables, timing, and instructor preparation is shown in Table 1. The instructor prepares a question focus for *Step 1—Question Focus,* which students use to generate questions in *Step 2—Produce Questions.* Students modify their questions in *Step 3—Improve Questions.* For *Step 4—Prioritize Questions,* students were asked to prioritize their questions to their top three questions based on: 1) interest to individuals and the team; 2) relationship to the requirements for the assignment; and 3) will likely be fun or engaging to present on. The QFT concludes with *Step 5—Reflect.* Each QFT activity took approximately 30 minutes of lecture time at the start and end of term, with students completing the activities in a Zoom break-out room during remote learning. Students completed the QFT activities on worksheets we collected after the class to allow us to count and code their questions and reflections after each QFT step.

## Analysis of Student Questions

We analyzed the questions students produced during the QFT process to understand student question development and experiences. To capture how productive the activity was in generating questions, we counted the total number of questions asked by all 20 teams during *Step 2—Produce Questions* (divergent thinking) and *Step 4—Prioritize Questions* (convergent thinking). To examine the variation in the number of questions asked per team, we plotted the counts per team in a box-whisker chart to compare medians and ranges.

To examine the content of the questions students asked, we coded each team's questions into five categories based on alignment with the four course themes (structure/function, ecology, evolution, applications) and "other" questions that were not aligned with course themes. Members of this study team independently coded each question, and any discrepancies in coding were discussed as a group until a consensus was reached. Each question students produced for Step 2 was coded to a single category. In contrast, some questions in Step 4 were coded to multiple categories due to having multiple ideas embedded in a single question. We then counted the number of questions aligned with each course theme.

To qualitatively visualize the content of the students' questions, we transcribed all the questions for each step and created word clouds using the online program WordArt. During transcription, we replaced words with multiple spellings (e.g., color/colour and behavior/behaviour), made all plural words singular, wrote out abbreviations and conjunctions (e.g., what's to what is), and removed "i.e., etc." The word cloud generator parameters included removing common words (e.g., what, where, and, the, how) to focus on keywords. All words were then colour-coded based on the category of the question asked for each word (e.g., if "eat" appears in a question related to ecology, it was coded green).

**Table 1**
*Timeline of 30-minute Implementation of the Question Formulation Technique, following the Right Question Institute's Question Formulation Technique (Rothstein & Santana, 2011)*

| QFT Step | Activity | Skills practiced | Student Deliverables | Timing | Instructor Preparation |
|---|---|---|---|---|---|
| 1) Question Focus | A visual image of invertebrate | Observation | N/A | 1 min | Prompt |
| 2) Produce Questions | Students ask as many questions as they can while following the rules: do not stop to discuss, judge, or answer any question; record questions exactly how they are stated; change statements into questions | Divergent thinking<br><br>Metacognition/ reflection<br><br>Collaboration/ teamwork | List of questions<br><br>Reflective responses | 2+ min. of question generation<br><br>2-5+ min. reflection & discussion | Display & discuss the rules<br><br>Display question prompt<br><br>Reflective questions |
| 3) Improve Questions | Students identify questions as "open" and "closed" and change closed questions to open and vice versa | Metacognition/ reflection<br><br>Collaboration/ teamwork<br><br>Analysis and examination of questions | Revised and/or coded questions<br><br>Reflective responses | 2+ min. question revision<br><br>2-5+ min. reflection & discussion | Examples of ways to revise questions (optional)<br><br>Discussion prompts around open vs. closed questions |
| 4) Prioritize Questions | Students prioritize their top questions based on criteria provided or developed | Convergent thinking<br><br>Metacognition/ reflection<br><br>Collaboration/ teamwork | Prioritized question(s)<br><br>Reflective responses | 5+ min. of prioritization & reflection | Criteria for prioritization |
| 5) Reflect | Students discuss and reflect on the process as a team or individually | Metacognition/ reflection<br><br>Collaboration/ teamwork | Written or verbal reflections | 5+ min. of reflection | Reflective prompts |

### Analysis of Student Feedback and Reflections

To better understand student experiences with QFT, we collected feedback and reflections after *Step 2—–Produce Questions* and *Step 4—Prioritize Questions* at the start of the term. Student teams were given the following prompts after Step 2: "What was your experience with thinking divergently? Was it easy or difficult? Did everyone talk? Do you feel excited or overwhelmed by your list of questions?" We analyzed the responses regarding contributions to the team, difficulty, and excitement vs overwhelmed. After Step 4, students were asked: "What are the advantages and disadvantages of the question formulation technique? What was most difficult? What was most helpful? Are there things you would do differently next time? When do you think this technique might be helpful in the future?" Student responses were transcribed and reviewed for themes, new ideas, and suggestions.

## Results

### Analysis of Student Questions

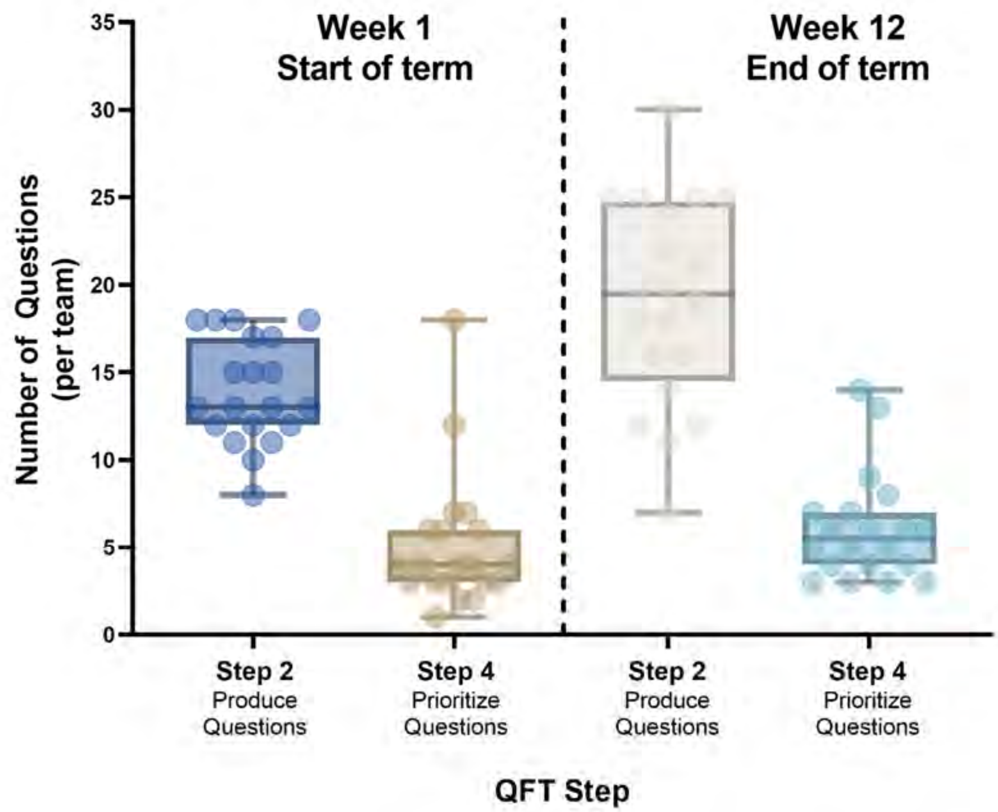
In less than five minutes, students asked a surprising number of questions. In the divergent thinking phase (Step 2), the class asked 279 questions at the start of the term, and 380 questions at the end of the term, a 36% increase in questions. The range in questions *per team* at the start of term was 8 -18, with a median of 13 questions per team. At the end of the term, the range was 7–30 questions per team, with a median of 19 questions per team (Figure 1).

For *Step 4—Prioritize Questions*, students were asked to identify their top three questions based on the criteria provided to the class. However, many teams struggled to prioritize their questions to only the top three. The average number of questions identified at Step 4 at the start of the term was 5.1 (range: 4-18) and 6.05 (range: 3-18) at the end of the term (Figure 1). This range of prioritized questions overlapped with the total number of questions asked in *Step 2—Produce Questions*.

Students asked questions broadly across the course themes, with an increase in application questions by the end of the term (Figure 2). At the start and end of the term, all questions were coded into five categories based on alignment with the four course themes: structure/function, ecology, evolution, applications, and "other" questions that were not aligned with course themes for each step. Students asked questions across all four course themes, with the highest proportion focused on *ecology* (30-39%) and *structure/function* (30-36%), followed by *evolution* (18-22%) and applications (4-12%), and only a very small proportion of questions *other/not aligned* with course themes (<1-4%) (Figure 2). While the total number of questions for each theme increased at the end of the term, the *proportion* of questions in each category remained relatively consistent, except the proportion of questions aligned with *applications* increased from the start to the end of the term.

**Figure 1**

*The Number of Questions Asked per Team for Step 2—Produce Questions and Step 4—Prioritize Questions during Week 1 and Week 12 of the Term*




To visualize the content and themes of student questions, we generated word clouds for Step 2 (279 questions and 174 unique, thematically coded words at the start of the term; 380 questions and 282 unique words at the end of the term) and Step 4 (102 questions and 76 unique words at the start of term; 121 questions and 138 unique words at the end of term) (Figure 3). The word clouds visually show the difference in student questions by the end of the term. At the start of the term, most questions focused on what invertebrates eat, which aligned with the course themes of structure/function or ecology. By the end of the term, students' questions were more distributed across course themes and topics, including questions about the environment, applications, phyla and evolutionary relationships, and structures. A list of example questions from the start and end of the term aligned with each course theme is provided in Table 2 to show differences in wording and content.

**Figure 2**
*The Total Number of Questions Asked Across All Terms Categorized by the Course Themes of Structure/Function, Evolution, Ecology, Applications, and "Other" at the Start and End of Term*

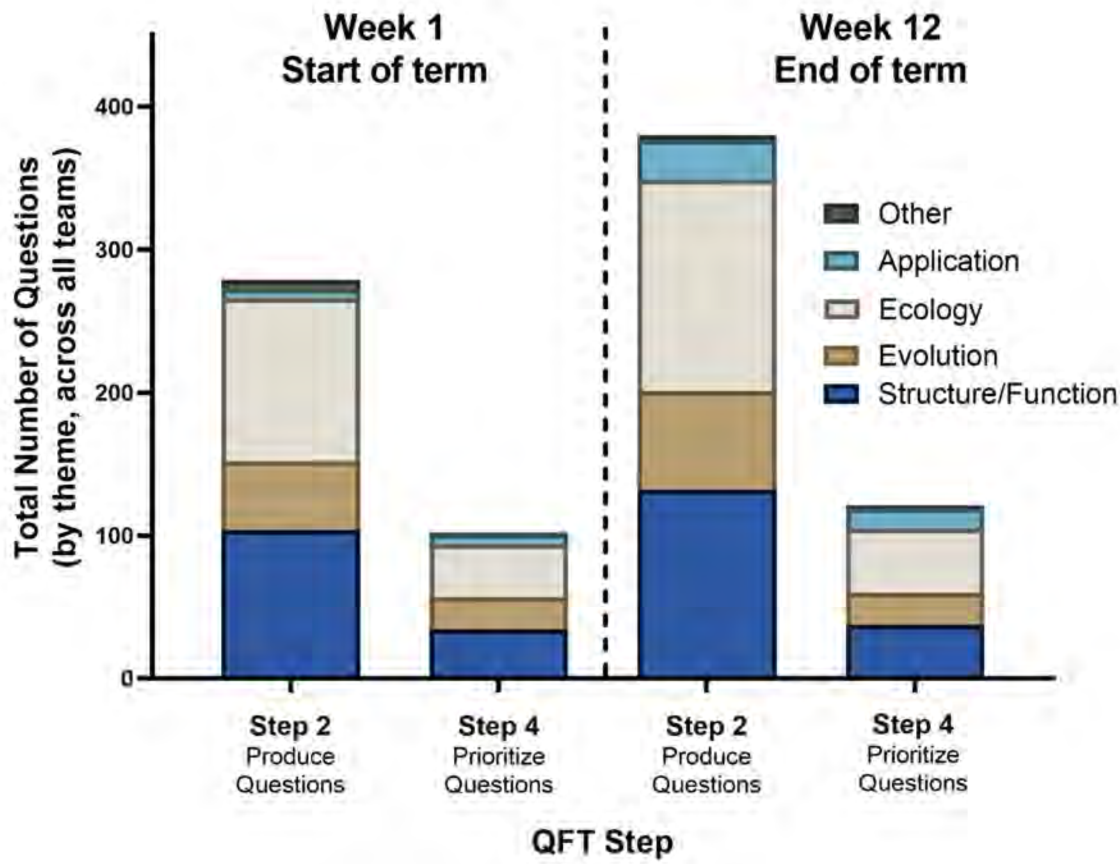
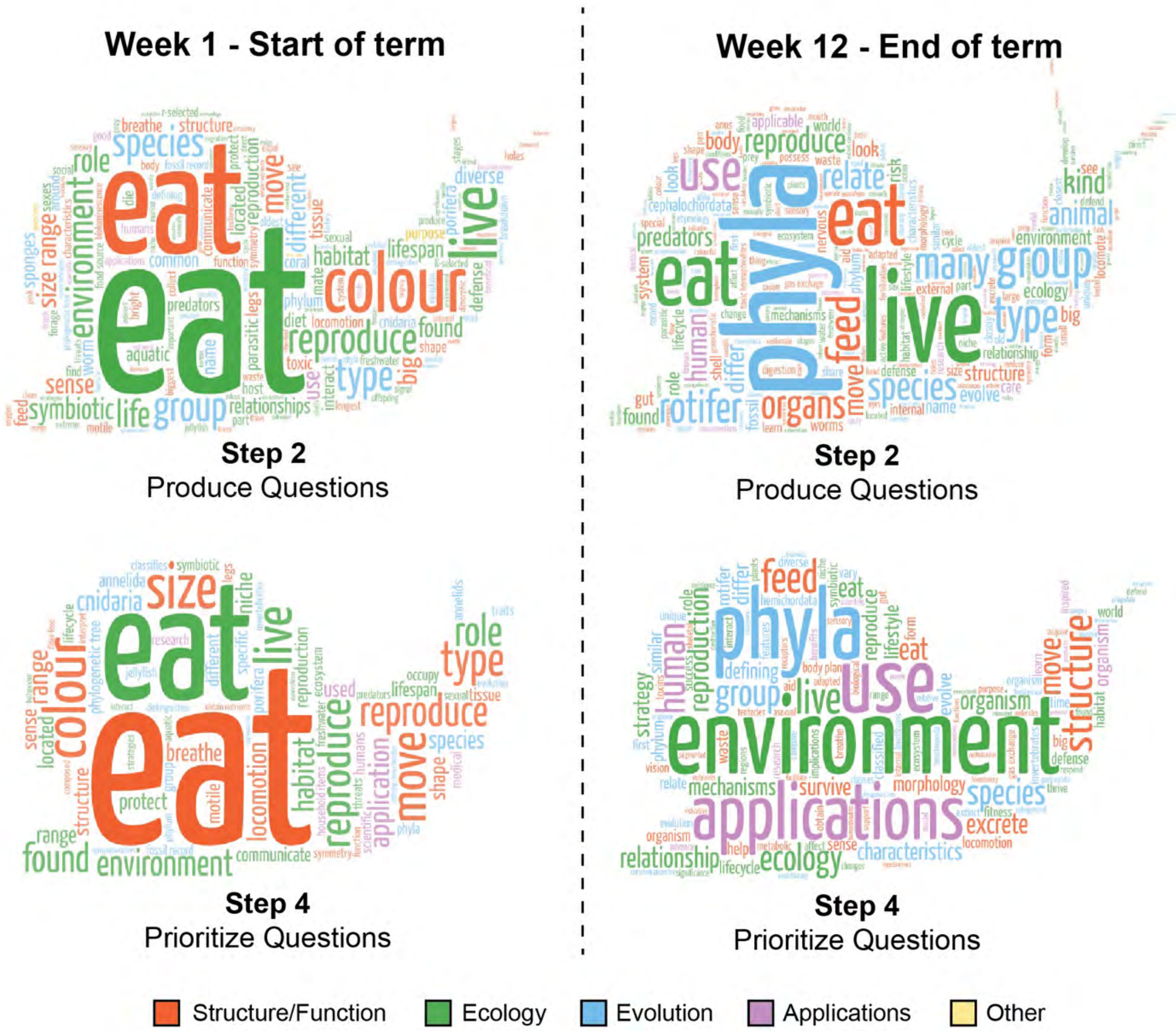


**Figure 3**

*Word Clouds of Keywords Included in Questions for Step 2—Produce Questions and Step 4—Prioritize Questions during Week 1 and Week 12 of the Term*




*Note.* Words are colour-coded based on the categorization of the question to the course themes: structure/function (orange), evolution (blue), ecology (green), applications (purple) and "other" (yellow)

**Table 2**

*Examples of Student Questions Asked for Each Course Theme during Step 2—Produce Questions, at the Start and End of the Term*

| Structure/function | |
|---|---|
| Start of Term | End of Term |
| • *How do they move/ do they move?*<br>• *How do they sense the environment around them?*<br>• *Can they communicate?*<br>• *Do they have a defense mechanism? Are any of them toxic?*<br>• *How do they clean themselves?*<br>• *What is their size range?* | • *What structures allow them to live, move, eat, and reproduce?*<br>• *How does this phyla move? What locomotion strategies do they use? Does it have a hydrostatic skeleton?*<br>• *Do they have cephalized nervous systems?*<br>• *Do they have sensory organs?*<br>• *How do major biological functions like gas exchange and digestion occur?*<br>• *Are they hermaphrodites or gonochoristic?*<br>• *Are there different forms of these organisms during their lifecycle?*<br>• *What is the basic morphology of this phyla? What does diversity in this phylum look like - body forms of species?*<br>• *How does their general morphology helps them survive and meet metabolic demands in various environments?* |
| **Evolution** | |
| Start of Term | End of Term |
| • *What distinguishes them from other invertebrates?*<br>• *When did they appear in the fossil record?*<br>• *Why are some parasitic?*<br>• *Why is there variation in body shape?*<br>• *How diverse is this phylum? How many species are there?* | • *How is this phyla related to other phyla we have learned about? What are the closest sister taxa to these groups?*<br>• *What is the evolutionary origin of this phyla? Is there a fossil record for these groups? How long ago did it evolve and what similarities does it still share with its oldest fossil ancestors?*<br>• *Throughout their evolution, how have they been categorized regarding other phyla? In other words, why were they once categorized as another phylum and then put into their own category later?*<br>• *What structures look similar to other organisms we have seen? How does this organism differ from other organisms in its phyla?*<br>• *What are its synapomorphies?* |

| Ecology | |
|---|---|
| Start of Term | End of Term |
| • *Where are they found? In what type of environment?*<br>• *What is their lifespan?*<br>• *What and how do they eat?*<br>• *What are its predators?*<br>• *How do they reproduce? Do they produce offspring by themselves or with a mate?*<br>• *Are they part of symbiotic relationships?*<br>• *Are they social?*<br>• *Is there parental care?* | • *Where are they located? Are they terrestrial, benthic, marine or freshwater? Are these organisms confined to certain depths in the ocean?*<br>• *What mechanisms of defense does this phyla have?*<br>• *Do we know what kind of food web/ecosystem this phyla is usually a part of? What role does this phyla play in its ecosystem?*<br>• *What stages does their lifecycle consist of? Do they develop directly or indirectly?*<br>• *How long do individuals live?*<br>• *In what areas of the world can this phyla be found and if introduced to different areas of the world could it be destructive to those ecosystems?*<br>• *Biological/ecological significance of their existence i.e. what would happen if they were to disappear?* |

| Applications | |
|---|---|
| Start of Term | End of Term |
| • *Are they used in medical or scientific research?* | • *Are they at risk (in need for conservation)?*<br>• *How will climate change affect them?*<br>• *Are there any uses or applications that humans have used for these animals?*<br>• *What are any possible medical applications?*<br>• *Does it include a model species for any field of research?*<br>• *Can they be a model for new technology?* |

## Analysis of Student Feedback and Reflections

Students reflected that the QFT process for producing questions was easy, with team members contributing equally and being excited by the questions generated. All 20 student teams provided reflections after *Step 1—Question Generation* in response to the prompts: "What was your experience with thinking divergently? Was it easy or difficult? Did everyone talk? Do you feel excited or overwhelmed by your list of questions?" (Table 3). All teams reported that they found QFT easy, with one team saying, “this experience was easy and positive. As a group, we are excited about our list of questions.” Thirteen teams (87%) reported that everyone in their group contributed; however, one team (7%) reported that not everyone contributed, and one team (7%) commented that some individuals felt uncomfortable contributing to a new group. The remaining five teams did not mention group member participation. Out of 20 teams, 12 (86%) shared that they were excited, interested, and intrigued by the questions their team developed. Two teams (14%) suggested that they were overwhelmed or slightly overwhelmed with the number of questions they came up with; however, one of those teams still referred to this as a “good experience.”

Students reflected that collaborative brainstorming was beneficial, but prioritizing questions was stressful and felt rushed. After completing the final QFT step, students were again asked to reflect on their experiences, with the following prompting questions: "What are the advantages and disadvantages of the question formulation technique? What was most difficult? What was most helpful? Are there things you would do differently next time? When do you think this technique might be helpful in the future?" Only nine of the 20 teams provided reflections; however, their responses were insightful. In terms of advantages, seven of the teams spoke to collaborative brainstorming being beneficial, that QFT was “helpful in gathering ideas and questions,” and that it was “fun to think of questions you don’t normally think about.” Teams were “able to get brainstorming very quickly.” Students commented that “creating questions led to more questions,” which allowed them to “think freely and out of the box.”

Regarding disadvantages, four teams commented that the discussion around prioritizing questions was challenging. During this step, some teams said that prioritizing was “stressful” and “people may dominate [the] discussion, while others shy behind” and that “it felt very rushed” and it was difficult when there were “conflicting ideas.” A team suggested that for prioritizing the questions, a helpful strategy was “finding questions, sorting them based on themes/importance” one team suggested that they “all write [questions] down, so one person doesn’t struggle.” When reflecting on how QFT might be helpful in the future, a team commented that this “technique is good for formulating in-depth questions (i.e., formulating hypotheses) and that it would be “helpful to use before lab or during projects [with] time constraints.”

**Table 3**
*Student Teams' Reflections on the QFT process after Step 2—Produce Questions.*

| Theme | Percentage (Proportion) of Comments by Theme | Representative Quotes |
|---|---|---|
| Equity of individual's contribution to the team | 87% (13/15) Everyone on the team contributed | "As a group it was very productive and supportive. Everyone asked at least two questions."<br><br>"Brainstorming was easy, everyone contributed. Drove excitement!" |
| | 13% (2/15) Not everyone on the team contributed *or* some individuals felt uncomfortable contributing | "It was easy, however not everyone participated. The list of questions is exciting."<br><br>"Relatively easy, everyone talked, slightly overwhelmed by the amount of questions. People were uncomfortable talking in a new group environment." |
| Easiness or difficulty of the process | 100% (16/16) Easy | "This experience was easy and positive. As a group we are excited about our list of questions."<br><br>"Enjoyed - now we have a place to start, seemed straightforward, easy, little effort; everyone talked/participated" |
| | 0% (0/16) Difficult | N/A |
| Excited vs overwhelmed by the questions | 86% (12/14) Excited or not overwhelmed | "Everyone contributed equally and the task was easy. We are excited to find the answers to our questions."<br><br>"Good experience, lots of questions came easily. Excited by list of questions." |
| | 14% (2/14) Overwhelmed or slightly overwhelmed | "Good experience. Everyone contributed. Think with open mind. No judgement. Overwhelmed. Surprised by how many we came up with." |

*Note*. Reflections are organized into themes of equity of contribution, easiness of the process, and whether students were excited or overwhelmed based on the reflective prompts. The percentage (proportion) of comments aligned to the theme is shown along with representative quotes.

# Discussion

## Experience with the QFT

The Question Formulation Technique (QFT) provides a structured way for students to generate questions collaboratively. Our analysis of student questions and reflections in an upper-division biology course highlight the benefits of practicing divergent thinking, the challenges of convergent thinking, and students' positive experiences with collaborative question generation.

During *Step 2 - Produce Questions*, students practice divergent thinking. After completing this step, students reflected that the process of producing questions was easy, with team members contributing equally, and students were excited by the questions generated. As facilitators, we find that during Step 2, students most struggle with not discussing the questions, and sometimes can be hesitant to start asking questions due to experiencing anxiety around what is a "good" question. It can be helpful to emphasize to students that this is a low-stakes activity not associated with any grades and it is an opportunity to practice asking questions and reflect on whether it is difficult to suspend judgement and discussion of others' questions. We also tell students that we are particularly looking for "messy questions" during this step, and that they will have opportunities to refine their question wording during later steps in the QFT. To encourage the participation of all team members, we also set an additional rule that each team member must suggest one question before anyone can pose a second question. In some settings, we have also used scented markers or coloured pens that can remind students of memories associated with childhood creativity.

During Step 2, students asked 279 questions at the start of term and 380 at the end of term. The total number of questions generated was 36% higher at the end of the term compared to the beginning. The higher number of questions asked per theme was likely a combination of multiple factors – for example, students learning more about each theme during the course, practice with divergent thinking, comfort in sharing ideas with their team members, and the switch to an online format where everyone typing at the same time may have resulted in faster question generation. As facilitators, we found this volume of questions exciting, particularly compared to lectures where only a few students may pose questions.

Using the QFT in this course also allowed us to better understand what topics students were curious about and interested in. The questions students generated were aligned with all four course themes. Interestingly, while the proportion of questions asked for each course theme remained relatively stable, there was an increase in the proportion of questions asked about applications (e.g., how invertebrates can inspire design or engineering, or how invertebrates are used in daily life). Applied biology, and in particular biomimicry or bio-inspired design, is highlighted in this course. Given the student interest observed through this QFT exercise, we have incorporated bio-inspired design into lectures, weekly discussion board assignments, and redesigned one laboratory.

*Step 4—Prioritize Questions* of the QFT was the most challenging for students in this course. Students reflected that they found collaborative brainstorming beneficial (Step 2), but prioritizing questions (Step 4) can be stressful and felt rushed. We also observed that many student teams struggled to prioritize their top questions to only three, with some teams who met the limit creating multi-part questions. Given that this step can feel rushed, we recommend letting students know that they will likely experience feeling rushed, and that there will be opportunities to follow-up and revise questions. It can also be helpful to explain that timing is provided because this is an exercise in developing collaborative skills and not formulating the "perfect" question. For this course, we gave the following three criteria to help student teams prioritize their final questions:

interest to you and the team; relates to the course themes; will likely be fun or engaging to present on. Given students' reflections on the discomfort felt during Step 4, instructors could also provide further resources for decision-making, such as rankings, scoring sheets, or ways to show each member's preferences (e.g., each team member receiving three stickers that they can distribute across questions). In other settings, we have also allowed students to take more time with this step. They begin Step 4 together in one lecture or lab session, and then complete this step during the next session.

From the instructional team perspective, one of the most exciting components of the QFT is the potential for growth in collaboration and teamwork over the term. Students also identified the benefits of collaboration in this course and in an undergraduate engineering course (Torres Garibay et al., 2020). We think a key benefit of QFT is that it can make what can be one of the most challenging parts of undergraduate inquiry and research fun. It is exciting to see students immediately engage their curiosity in question generation, especially at the start of a term. We also have similar observations as Torres Garibay (2020), where, by providing a structured activity for generating questions, the QFT helps to personalize student learning and increase participation in class. We also think QFT can help reverse students' common misconception that they can only ask questions or engage in research once they know and understand the entire body of disciplinary knowledge. To encourage fun and creativity in the QFT, we agree with Vale (2003) that it is important to create a safe environment where questions are not judged as high or low quality. Since question generation and collaboration are both important aspects of scientific inquiry, we think it would be interesting to investigate further whether engaging in QFT may help students see themselves as scientists earlier in our undergraduate programs.

In future iterations of the QFT, we are interested in having students use the summary descriptions created here (counts and word clouds) to further reflect on their process. Other options to expand the QFT could include having students categorize their questions using a questioning taxonomy (for depth of question) (e.g., Marbach-Ad & Sokolove, 2000), and compare the number and depth/content of their questions (Berry & Chew, 2008; Chin & Osborne, 2008; Etkina, 2000; Harper et al., 2003; Marbach-Ad & Sokolove, 2000). Resources likewise exist to help students with formulating and reframing questions (e.g., Badia, 2016; King, 1989; Molina-Alarcon et al., 2015). As instructors who use QFT in various settings (lecture, laboratory, field courses), we are also interested in better understanding how setting, team size, and opportunities to practice with the QFT impacts the student experience.

## Opportunities to use QFT in undergraduate courses and research experiences

From our findings and experiences, we believe that the QFT can be applied in a range of disciplines and university settings to engage student curiosity and develop skills in question generation and collaboration. In our courses, we have QFT in a variety of learning contexts, including course-based research experiences, community-engaged learning, international collaborations, and independent research projects. The number of students engaging in QFT in our courses has ranged from 24 to over 350. Following QFT, we typically take student teams through exercises to refine their questions to meet logistical constraints or objectives (e.g., one-term or one-year project; funding deliverables). For example, research question frameworks can be used to take a question generated during QFT and refine it to become a researchable question (e.g., Molina-Alarcon et al., 2015; Richardson et al., 1995). The final questions have led to various student investigations and methods (observational, hypothesis-based, natural experiments, modelling, etc.). Across these settings, we use the QFT to engage students in scientific discovery and curiosity. We re-orient students away from products (e.g., grades) towards the *process* of science and collaboration. Overall, we would like to emphasize that our success with using QFT has largely resulted from building a community of practice among instructors using the QFT to share recommendations, as well as research collaborations with current students to better understand and improve student experiences.

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