What Biology Concepts are Important in General Education?:
A Survey of Faculty Members and Students

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Abstract
What are the most important concepts to teach in an introductory non-majors biology course? A survey including 17 core biological topics was compiled and then distributed to Life Science professors at Brigham Young University and Utah Valley University to identify the most critical topics to be included in such a course. Upon the completion of this initial distribution, the survey was then given to students in an introductory non-majors biology course as well as an introductory biology course for science majors. This study revealed that although there are no differences among professors from separate universities, there are significant discrepancies among what teachers and students deem to teach is such a course. Upon the completion of this initial distribution, the survey was then given to students in an introductory non-majors biology course as well as an introductory biology course for science majors. This study revealed that although there are no differences among professors from separate universities, there are significant discrepancies among what teachers and students deem to teach is such a course. The students ranked evolution, ecology, and scientific reasoning much lower in importance compared to the faculty. This ranking reveals that students do not understand some of the key points of basic biological concepts in the bigger world of biology. Failure to instill the importance of such critical topics greatly inhibits the establishment of a well-informed citizen scientist among the general populace.

Introduction
There has been a nation-wide push to develop learning outcomes for all university courses, in order to set a standard for what students should know upon completion of a course. However, as noted in the literature, college students coming out of introductory courses show a surprising lack of understanding (NRC, 1997) about basic biology concepts and principles such as evolution (Alters and Nelson, 2002) and ecology (Mason, 1992) and even significant chronic misconceptions about key ideas such as the importance of scientific reasoning. In order to combat this rising phenomenon, some investigators (Bransford, Brown, and Corking, 1999) have reported...
that students are more likely to develop usable knowledge if teachers give repeated feedback on student understanding. It is also deemed important for teachers to allow students time, both in laboratory and lecture, for principles to stimulate understanding and creative thinking (Crow, 2004). However, even when feedback is provided and students are given time to ponder the principles, it has been repeatedly noted that many students still do not understand why certain topics are included in a course. Students often consider them “boring” or unrelated to their career path. Hence, the intent of the present study is to evaluate what themes in biology are important to learn, from both a student and a faculty point of view, so that desirable course outcomes can be established and student perceptions of these outcomes can be evaluated.

A survey was conducted in which each participant (student and faculty member) was asked to rank seventeen themes in biology from the most important to the least important. These themes were chosen by the authors of the survey, with input given by other life science professors involved in teaching introductory biology courses at Brigham Young University (BYU) and Utah Valley University (UVU). Based on a sampling of introductory biology textbooks most frequently used at the two institutions (Campbell et al., 2008; Starr and Taggart, 2008; Raven et al., 2008), the seventeen topics were key themes covered in all three of the introductory biology textbooks reviewed. This survey revealed surprising discrepancies in the learning outcomes expected by students and by teachers. The current results reflect the outcome for students at only a single university and the life science faculty of two universities, but it would be interesting to learn whether administering the survey at multiple institutions would produce a similar outcome.

Following this initial distribution, the survey was then distributed to students who were in Dr. Gary M. Booth’s non-majors Biology 100 class the previous semester and students who were just completing Biology 120, an introductory biology course for science majors at BYU. The survey was taken at the end of the semester, after the course curriculum was completed. Students also included their demographic information (year in school, current course, etc.). There were 66/105 non-major students, 352/621 major students, and 64/86 faculty participants in the study. (The numerator is the number of respondents compared to the denominator, the population surveyed.) A comparison among non-major biology students, biology major students, and professors was then conducted to determine the rankings of each group and compare differences. All of the returned surveys were completely filled out, i.e. there were no missing data.

The courses for majors and non-majors were taught in a similar fashion. They were both typical classroom settings with lectures and exams, and neither class involved research or lab work. Both major and non-major classes that were surveyed were composed primarily of freshmen.

**Measures**

The survey contained seventeen concepts to be ranked from one (most important) to seventeen (least important). These concepts were chosen based on topics traditionally included in introductory biology textbooks (Campbell et al., 2008; Starr and Taggart, 2008; Raven et al., 2008). These themes were:

- Scientific Reasoning/Method
- The Cell
- Evolution
- Cell Division
- Biological Molecules
- The Central Dogma
- Mendelian Genetics
- Ecology
- Bioenergetics (cellular respiration)
- Photosynthesis
- Metabolism and Enzymes
- History of Science
- Fundamentals of Chemistry

**Methods**

This survey was sent to BYU life science professors and UVU life science professors and asked the professors to rank a list of seventeen biological concepts from the most to the least important for non-majors in an introductory biology course. Professors also included their demographic information on this survey (education, current job, subject taught, etc.).
A copy of the survey can be found in Appendix A.

Statistical Analysis
A one-way Analysis of Variance Between Groups (ANOVA) was used to analyze the mean rankings of each of the seventeen concepts for professors, non-major, and major students. When there were significant differences (significant F test), an LSD (least significant difference) post hoc test was conducted to find where the differences were. An LSD test can be used when significance is found in the ANOVA, and LSD provides the most power. Significance was $\alpha \leq 0.05$.

Results and Discussion
The three concepts most frequently ranked as important by professors were: Scientific Reasoning (3.78 average ranking), The Cell (4.11), and Evolution (5.38). The bottom three concepts were Viruses (13.95), Immunology (13.52), and Embryonic Development (12.95). These data differed significantly from those of the non-majors (Biology 100) and majors (PDBio 120), who ranked (on average) the following as the top three concepts: The Cell (3.15 non-majors, 3.32 majors), Cell Division (5.82

<table>
<thead>
<tr>
<th>Concept</th>
<th>Faculty Average Ranking</th>
<th>Non-major Students Average Ranking</th>
<th>Major Students Average Ranking</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evolution</td>
<td>5.38</td>
<td>11.11</td>
<td>11.14</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Fundamentals of Chemistry</td>
<td>10.25</td>
<td>10.40</td>
<td>9.43</td>
<td>0.248</td>
</tr>
<tr>
<td>The Cell</td>
<td>4.11</td>
<td>3.15</td>
<td>3.32</td>
<td>0.116</td>
</tr>
<tr>
<td>Bioenergetics</td>
<td>8.63</td>
<td>9.38</td>
<td>8.58</td>
<td>0.348</td>
</tr>
<tr>
<td>The Central Dogma</td>
<td>7.67</td>
<td>6.26</td>
<td>7.34</td>
<td>0.231</td>
</tr>
<tr>
<td>Immunology</td>
<td>13.52</td>
<td>9.71</td>
<td>11.51</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Viruses</td>
<td>13.95</td>
<td>9.80</td>
<td>11.05</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Cell Division</td>
<td>7.27</td>
<td>5.82</td>
<td>5.95</td>
<td>0.042*</td>
</tr>
<tr>
<td>Mendelian Genetics</td>
<td>7.83</td>
<td>8.14</td>
<td>9.70</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Metabolism and Enzymes</td>
<td>9.14</td>
<td>7.83</td>
<td>7.96</td>
<td>0.043*</td>
</tr>
<tr>
<td>Photosynthesis</td>
<td>8.84</td>
<td>8.36</td>
<td>7.74</td>
<td>0.076</td>
</tr>
<tr>
<td>Plant Reproduction</td>
<td>12.38</td>
<td>12.05</td>
<td>11.28</td>
<td>0.059</td>
</tr>
<tr>
<td>Biological Molecules</td>
<td>7.83</td>
<td>5.50</td>
<td>5.37</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Embryonic Development</td>
<td>12.94</td>
<td>9.68</td>
<td>10.68</td>
<td>0.0001*</td>
</tr>
<tr>
<td>History of Science</td>
<td>9.91</td>
<td>13.15</td>
<td>11.76</td>
<td>0.002*</td>
</tr>
<tr>
<td>Scientific Reasoning</td>
<td>3.78</td>
<td>9.44</td>
<td>6.56</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Ecology</td>
<td>8.03</td>
<td>12.00</td>
<td>12.17</td>
<td>0.0001*</td>
</tr>
</tbody>
</table>

*Statistically significant $p \leq 0.05$
From the faculty, major, and non-major student treatments, there were eleven significant (p ≤ 0.05) differences among the mean scores. The differences and their p values found were as follows: Evolution (p = 0.001), Immunology (p = 0.001), Viruses (p = 0.001), Cell Division (p = 0.014), Mendelian Genetics (p = 0.001), Metabolism/Enzymes (p = 0.043), Biological Molecules (p = 0.001), Embryonic Development (p = 0.001), History of Science (p = 0.002), Scientific Reasoning (p = 0.001), and Ecology (p = 0.001). Table 1 summarizes the average ranking for all of the concepts and the p-values, indicating which were significant (p ≤ 0.05). Tables 2, 3 and 4 provide a visual summary of how the three different groups (professors, non-majors, and majors) ranked the seventeen concepts in order of importance.

The LSD post hoc data indicate significant differences (p ≤ 0.05) between faculty and science majors in all of the following eleven areas: Evolution, Immunology, Viruses, Mendelian Genetics, Metabolism and Enzymes,
Biological Molecules, Embryonic Development, History of Science, Scientific Reasoning/Method, Cell Division and Ecology. Comparisons between faculty and non-major biology students also had significant differences (p≤ 0.05) in all of the areas listed above with the exception of Mendelian Genetics and Metabolism and Enzymes.

There were also significant differences between average rankings from non-major and major students for the following concepts: Immunology, Viruses, Mendelian Genetics, History of Science, and Scientific Reasoning/Method (Table 5).

**TABLE 5.** Significant differences in rankings between major and non-major biology students.

<table>
<thead>
<tr>
<th>Concept</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immunology</td>
<td>0.0001</td>
</tr>
<tr>
<td>Viruses</td>
<td>0.015</td>
</tr>
<tr>
<td>Mendelian Genetics</td>
<td>0.003</td>
</tr>
<tr>
<td>History of Science</td>
<td>0.047</td>
</tr>
<tr>
<td>Scientific Reasoning/Method</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

1Non-major students ranked these concepts as more important than major students did.
1Major students ranked these concepts as more important than non-major students did.

Faculty ranked Evolution and Ecology as two of the most important concepts to teach; students ranked them as two of the least important. This is perhaps the most surprising of all the data. Evolution is the capstone of all biology and thus, it was unexpected that students would place it near the bottom in terms of importance. However, others have suggested a similar concern (Alters and Nelson, 2002), and therefore teachers need to investigate methods to improve understanding of how evolution can best be integrated into biology courses. The National Research Council has recently shown (NRC, 2012) that approximately 40% of all the people in the US “believe” that evolution is false; and 32% of students with a college education think that evolution is not based on a solid scientific foundation. Indeed, 40% of high school biology teachers doubt the validity of the theory of evolution. Much of our students’ thinking on this issue has been framed early in their education both in the home and in formal education. Thus, in a college classroom we often hear our freshmen students whisper, “Here it comes again.”

Ecology is another great concern. Ecology helps students see the “big picture” instead of learning random facts, which often causes students to dislike science (Mason, 1992). In his book *The Diversity of Life*, Wilson...
(1992) discusses the importance of ecology and describes biodiversity as priceless and an important part of humanity. Wilson (2006) argues there is a bond between humans and other species, and that we subconsciously seek these connections with the rest of life (Wilson, 1992). He has also suggested that students can integrate and make connections to all aspects of biology only if they are introduced to the “big picture” of biology, early in the course. He calls this “teaching from the top down.” The survey results indicate that professors recognize the key role of ecology, but once again this study reveals that this key concept is not adequately understood and/or communicated to the students.

The discrepancy between faculty and student ratings on scientific reasoning/method is also interesting. Scientific reasoning skills are the foundation of experimental biology and science as a whole and are clearly needed for the citizen scientist (Burns, 2012); however, Tyser & Cerbin (1991) explained that teachers are often unsure how to teach thinking skills and how to incorporate this concept into their courses without sacrificing content. These data suggest that if the goal is to help create more scientifically literate citizens, a more concerted effort should be placed on using scientific reasoning as an active learning pedagogy.

There were significant differences in rankings between biology major and non-major students, but they were more consistent with each other than when the rankings were compared to faculty. The most significant difference among the students was scientific reasoning/method, with majors ranking this topic as more important than did the non-major students. STEM major students are often more exposed to scientific research and perhaps have more opportunity to see the importance of the scientific method and reasoning skills. Even though the course for majors is also an introductory course, students who have chosen biology as a major are more often already involved in some type of research or are taking other science courses simultaneously. Most non-major students will only take an introductory biology course at college in order to satisfy a general education requirement; therefore focus should be placed on skills like scientific reasoning, that will most improve the ability of a citizen scientist to reason and make rational scientific decisions that will impact communities for years to come. Given this scenario, perhaps our best and most creative teachers should be given the assignment of teaching our non-major students.

Another hypothesis that could explain the difference between majors and non-majors is how the biology course is taught for these two different student populations. Perhaps the majors-level course puts more emphasis on scientific reasoning because it will be a necessary skill for future major courses and lab work. However, as explained previously, it would be shortsighted to think that only those students majoring in science need to be scientifically literate and have the ability to reason and make scientific decisions.

Finally, the way in which textbooks are designed may also be contributing to the lack of theme integration (especially for ecology and evolution) as the students move from topic to topic. For example, Duncan et al. (2011) have shown that <5% of the figures used in textbooks (including those used in our study) stimulate creative thinking and scientific reasoning. These authors state that “… a lack of emphasis on the process of scientific investigation in the figures that appear in introductory college textbooks is an impediment to students’ understanding of science.”

**Conclusions**

Faculty ranked the importance of eleven of the seventeen biology concepts in a significantly different order than the students. Evolution was ranked as one of the most important concepts for faculty, whereas students ranked it much lower. Ecology was ranked as least important by major students and third to lowest by non-major students, but was ranked much higher by faculty. Scientific reasoning/method was also ranked by faculty as one of the top three most important concepts to teach, while students ranked it significantly lower in importance. These results indicate that students are not learning or understanding the importance of what faculty view as the key concepts in biology. Evolution is the capstone of biology, and ecology is vital for understanding the “big picture” of biology. A clear understanding of these two concepts is a must for our citizen scientist. Scientific reasoning and the scientific method are the driving forces behind all experimental
More time needs to be devoted to the process of science so that an appreciation for scientific reasoning will sink in. The outcomes in this investigation may reflect previous student exposure to or experience with these biological concepts (in their homes, perhaps). This is probably why a large proportion of US citizens do not accept evolution as a vital capstone of all biology. We believe this study should be repeated on a larger scale, with faculty and student participants from throughout the nation, in order to evaluate the severity of the discrepancy between faculty and student perspectives of what is truly relevant in biology. The design of the illustrations in our textbooks clearly needs to be improved so that our students can see the value of scientific reasoning. This will undoubtedly help them see connections from theme to theme. It is hoped that all students leave their biology courses with the ability to apply biological principles in their lives, to help them recognize the importance of biology and to allow them the opportunity to solve real-world problems in their community, the nation, and the world.

### About the Authors

**Jessica Howell** received her B.S. and M.S. degrees from Brigham Young University. This manuscript is part of her research she completed for her M.S. degree (2010) in the Department of Plant and Wildlife Sciences.

**Michelle McDonald** received her B.S. degree from Brigham Young University in 2012, and has worked closely on this project as part of her undergraduate mentoring research experience.

**Patricia Esplin** is Emeritus Director for the Freshman Mentoring Program at Brigham Young University. Pat received her B.S. from Brigham Young University and her Ph.D from University of Utah. She continues to be involved at the national and international level in novel ways to engage students in the learning process and to teach them how to be life-long learners.

**G. Bruce Schaafle** is a Professor of Statistics at Brigham Young University and currently teaches the beginning course in statistics for non-majors. Bruce received his B.S. and M.S. degrees from Brigham Young University. Bruce received a M.S. from the University of Washington and Ph.D from North Carolina State University. He consults with many departments on campus as a valued member of their research teams. He is particularly interested in helping our students understand the importance of statistics in the real world.

**Gary M. Booth** is Professor of Plant and Wildlife Sciences at Brigham Young University. He received his B.S. and M.S. degree from Utah State University and a Ph.D from University of California, Riverside, all in entomology. Gary has taught Biology 100 as a Freshman Mentoring faculty for over 40 years. He was responsible for bringing service learning as an integral part of Biology 100 curriculum and is serving as a Leadership Fellow for a grant from the Keck Foundation in the development of the Nodal Program established through SENCER. He has been an active participant of SENCER for over 15 years.

### References

- Burns, D. 2012. Personal communication.
MASTERS RESEARCH SURVEY

Dr. Gary Booth, Professor of Wildlife and Sciences at Brigham Young University, and his graduate student Jessica Rosenvall are performing a Masters thesis research project developed around seventeen biological concepts that should be taught in an introductory General Education biology class.

Please fill out the following information:
Your name (first and last) ________________________________________________
University where you work ________________________________________________
Your Department ________________________________________________________
Are you currently teaching? ________
If yes, which courses? ____________________________________________________
If not, what do you do at the University? _________________________________
Your age _________

Please rank the following list by what you would consider to be the most important concepts to teach in an introductory non-major General Education biology class.

Rank the terms with:
1 = most important concept to teach through 17 = least important to teach.

Write the numbers on the lines preceding these concepts.

_____ Evolution
_____ Fundamentals of chemistry
_____ The cell
_____ Bioenergetics (cellular respiration)
_____ The Central Dogma
_____ Immunology
_____ Viruses
_____ Cell Division (mitosis and meiosis)
_____ Mendelian Genetics
_____ Metabolism and Enzymes

_____ Photosynthesis
_____ Plant Reproduction
_____ Biological molecules (carbohydrates, proteins, lipids, nucleic acids)
_____ Embryonic Development
_____ History of Science
_____ Scientific Reasoning/scientific method
_____ Ecology

_____ Please put an X on this line if you give your consent to use your answers in our study.
    We will not attach names to the study but will review the data as a whole.

Thank you for your help. You can put this survey in Dr. Booth's box in the PWS office, sent it to his office (419 WIDB) or email it to us at gary_booth@byu.edu