ARTICLE

A Proposal for a Common Minimal Topic Set in Introductory Biology Courses for Majors

EILEEN GREGORY, JANE P. ELLIS, AMANDA N. ORENSTEIN

Abstract

A common complaint among instructors of introductory biology is that the courses cover too much material. Without a national consensus specifying which topics are essential, instructors are leery of excluding material. A survey was administered to two-year college and four-year college and university section members of the National Association of Biology Teachers to identify the topics and skills that college and university biology instructors believe students completing introductory biology should know and comprehend. Analysis identified a strong consensus for 20 topics and seven skills that should be included in all year-long introductory college biology course sequences for majors.

Key Words: *Introductory biology; content topics; skills; college biology; essential topics.*

Problems with introductory college biology courses for majors have been the focus of several recent reports (Committee on Undergraduate Biology Education, 2003; Smith et al., 2005; Timmerman et al., 2008). Our personal experiences and conversations with colleagues reveal that students enter these courses expecting to gain a deeper understanding of the structure, function, and importance of living organisms. Faculty hope to provide students with a solid foundation in biological principles that can be built upon in advanced biology courses. However, both often leave the course frustrated. Studies have shown that lecturing to a large class generally does not lead to the development of critical-thinking skills and is more likely to discourage students from majoring in the sciences than to motivate them to pursue advanced studies in biology (Labov, 2004; McDaniel et al., 2007; Timmerman et al., 2008; Wood, 2009). A large body of research shows that the incorporation of active-learning strategies can lead to the desired student learning outcomes and can excite students about the subject material (Smith et al., 2005; Cooper et al., 2006; McDaniel et al., 2007; Regassa & Morrison-Shetlar, 2007; Morse & Jutras, 2008). The College Board has recognized the problem in the Advanced Placement (AP) Biology curriculum and is ready to implement a redesigned curriculum in AP Biology that focuses on the process of science and skills development rather than the memorization of facts (Wood, 2009). With the obvious need for change, the question arises as to why reform has occurred in only a minority of introductory biology courses.

> *Expansion of the biological sciences has already led to instructors trying to cover more material in the same amount of class time.*

Instructors of introductory college biology commonly comment that there is not enough time to cover all of the material. Conversations with colleagues indicate that faculty are concerned that incorporation of active-learning activities, case studies, and open-ended investigations will leave less time for content. As new discoveries broaden the field of biology, the issue of time will become even more of a problem. It has been suggested that expansion of the biological sciences has already led to instructors trying to cover more material in the same amount of class time (Wood, 2009). The perceived pressure to introduce students to every topic in biology is most likely reinforced by encyclopedic textbooks, and by the belief that colleagues at other institutions cover all aspects of biology. It is ironic that unlike for chemistry (American Chemical Society, 2008), there is no common or national curriculum for college biology, so the conviction that a certain amount of material must be taught in introductory courses is in reality a self-imposed constraint. Some faculty additionally argue that instructors of advanced biology courses require the basic concepts of their field to be taught in the introductory course sequence. However, lecturing on a subject does not mean that the students have sufficient understanding to either apply or build upon the concepts in more advanced classes. The argument for a broad but shallow curriculum also loses strength when one considers the inconsistency among introductory college biology courses. The topics covered in depth vary greatly within and across institutions and often are more a reflection of personal interest than of pedagogical reasoning (N. Bernstein, unpubl. data).

Given the diverse backgrounds and interests of biology faculty, it is unlikely that a national curriculum for introductory biology for majors could be agreed upon (Cheesman et al., 2007). The authors set out to determine whether substantial agreement among college and university instructors could be found, however, for limiting the topics covered. The premise was that if there were widespread agreement on the minimal concepts and skills that students successfully completing introductory biology should know, understand, and be able to apply, then instructors of advanced biology courses could be assured of the background knowledge of their students. Likewise, identification of topics that students are expected to have learned prior to starting college would help

The American Biology Teacher, Vol. 73, No. 1, pages 16–21. ISSN 0002-7685, electronic ISSN 1938–4211.
DOI: 10.1525/abt.2011.73.1.4

inform high school teachers of expectations for their courses by college faculty. Inconsistency in topic coverage can also place transfer students at a disadvantage. With a common minimal core of topics, transfer students would be prepared for advanced work regardless of where they initiate their college career. Most importantly, if the course were designed to cover no more than one topic or concept per week, instructors would have the time and freedom to utilize teaching methodologies that foster deeper student understanding; develop laboratory, analytical, and communication skills; prepare students for assessment measures; and excite students about historically important discoveries in biology.

A national consensus on the minimal topics to be covered in depth in introductory biology would have the advantage of maintaining freedom for each instructor to design his or her course to best suit the needs of their students and their own interests. Unlike with a defined national curriculum, instructors would have the freedom to cover more topics if time or interest permits. The goal of this project was to delineate the minimal topics that must be learned by students in introductory biology. While some may argue for a national curriculum, the development of a list of minimal topics could be agreed upon and implemented in a more timely manner. Such an agreement is possible, given that consistency in at least 12 topics in introductory biology has been reported (Cheesman et al., 2007).

The authors built upon a preliminary study (E. Gregory & J. Moore, unpubl. data) and attempted to identify 25 topics that all students completing introductory biology for majors should know and understand. The number of topics was set at 25, on the assumption that all year-long course sequences for majors have at least 25 full weeks of instruction. Members of the Two-Year and Four-Year College Sections of the National Association of Biology Teachers (NABT) were surveyed on topics and skills appropriate for this course sequence; the responses were analyzed to determine whether a consensus on the material to be taught is likely.

○ Methodology

A three-question Zoomerang online survey was developed on the basis of the data from the preliminary study by Gregory and Moore. The preliminary survey consisted of 39 topics and was administered to a self-selected group of two-year and four-year faculty at the 2008 AP Biology Reading. The list of topics was developed on the basis of a survey of existing syllabi and texts commonly used in introductory biology courses. Additionally, 18 analytical and laboratory skills were identified on the basis of the authors' experiences and a review of typical laboratory exercises used in general biology. The preliminary survey was modified and an online version was pretested on a small group of NABT members (n = 18). After slight modifications to the directions for clarity, the survey was sent via e-mail in the spring of 2009 to all members of the Four-Year College and University Section of NABT (n = 750). This was followed up over the next 4 weeks with two e-mail reminders about the survey. One month later the same survey was sent via e-mail to all members of the Two-Year College Section (n = 525); this was followed by one e-mail reminder.

The first survey question required respondents to classify 41 topics as either "Essential" (essential for an introductory biology course sequence for majors), "Prior Knowledge" (topic that should have been learned prior to college), "Higher Level" (more appropriate for a higher-level biology course), or "Not Essential" for biology majors. Instructions requested that the respondent limit his or her selection of topics classified as "Essential" to 25, however, the survey instrument did not allow adherence to this direction to be controlled or monitored. The second survey question asked the respondents to select from a list of 21 skills those that should be developed in a year-long introductory biology course sequence for majors. There was no limit to the number of skills that could be identified for inclusion in this type of course. The last survey question provided an opportunity for participants to share comments about the survey.

○ Results

Survey

The online survey was completed by 227 of the 750 NABT members teaching at four-year (4Y) institutions (30.3% response rate). The response rate was much lower for faculty at two-year (2Y) institutions (n = 83, 15.8%), perhaps reflecting the timing of the survey. The survey was e-mailed to faculty at 4Y institutions in March 2009, with two reminders. The survey was not e-mailed to faculty at 2Y institutions until early May 2009, with one reminder. Both surveys were closed 1 month after the initial e-mail invitation. The lower response rate for the 2Y cohort may reflect that spring courses ended prior to survey distribution and that many 2Y faculty do not teach during the summer. Fifty-nine individuals (4Y = 40 and 2Y = 19) took advantage of the opportunity to provide comments about the survey or the project.

Essential Topics

The first section of the online survey asked faculty to select 25 topics as "Essential" to be included in an introductory course sequence for biology majors from a list of 41 topics. The 16 topics not selected as "Essential" were categorized as "Prior Knowledge," "Higher Level," or "Not Essential." The topic most frequently (89%) identified as "Essential" was evolution, including mechanisms and phylogeny (Table 1). Evolution was identified by 5% of faculty members as "Prior Knowledge," by 5% as "Higher Level," and by only 1% as "Not Essential" (see defintions of these terms above). The related concept of speciation was also selected as "Essential" by 73% of faculty members (7% "Prior Knowledge," 19% "Higher Level," and 1% "Not Essential").

Of the 25 topics most commonly categorized as "Essential," on average only 1% (and not >6%) of the respondents identified these topics as "Not Essential." When the top 10 "Essential" topics were not selected by a faculty member as "Essential," they were selected most frequently as "Prior Knowledge," with the exception of evolution, which was equally selected as "Prior Knowledge" and "Higher Level." This indicates that the top 25 "Essential" knowledge areas are widely perceived as critical in the education of biology majors at undergraduate institutions.

Topics falling below the top 25 "Essential" topics were most frequently categorized as "Higher Level" and included diversity outside of the animal and plant kingdoms, animal and plant anatomy and physiology, and animal and plant development knowledge areas (Table 2). The top 25 "Essential" topics all fell at or below 45% in the "Higher Level" category. Multiple faculty members indicated in their comments that it was difficult to categorize a topic as "Essential" or "Higher Level" and felt that the introductory course sequence should include the topic at a broad level and then be studied in greater depth in a higher-level course.

In general, 4Y and 2Y faculty members agreed regarding the ranking of "Essential" topics. The top 21 "Essential" topics were shared between both groups, with minor variations in their exact ranks. The next six topics showed some differences between groups, but again the exact rankings were only slightly different. The bottom 14 topics were also shared between groups with only minor differences in rankings.

Skills Development

In the second section of the survey, faculty were asked to select skills in which students should be proficient upon completion of an introductory biology course sequence for majors. Any number of skills could be selected from the list of 18 in the preliminary survey given to the self-selected 2Y and 4Y college faculty attending the 2008 AP Reading and from the list of 21 in the online version given to the respective section members of NABT.

In the preliminary survey, respondents could select any number of skills as "Essential" for proficiency upon completion of the introductory course sequence and had the option to identify skills in which students should be proficient prior to taking this course sequence (Figure 1). This survey identified a large number of skills, such as graphing, making observations,

Table 1. Topics ranked by the percentage of respondents (n = 310) who identified the topic as "Essential." Bold and shaded topics are those that were ranked within the top 25.

4-year rank	2-year rank	Combined rank	Topic	Essential (%)	Prior Knowledge (%)	Higher Level (%)	Not Essential (%)
1	1	1	Evolution (mechanisms, phylogeny)	89	5	5	1
2	5	2	DNA structure and replication	86	12	1	0
5	4	3	Membranes and transport	86	9	4	1
4	6	4	Protein synthesis	86	9	5	0
6	3	5	Respiration	86	10	3	0
3	7	6	Photosynthesis	85	10	4	0
9	2	7	Enzymes	78	13	8	0
7	9	8	Meiosis	78	21	1	0
10	8	9	Cell cycle	75	21	3	0
8	11	10	Mendelian genetics	75	21	4	0
11	12	11	Ecosystems and conservation	74	12	13	1
12	10	12	Speciation	73	7	19	1
13	14	13	Cell structure (prokaryotic and eukaryotic)	69	30	1	0
15	13	14	Genetic recombination and mutations	68	5	26	0
14	16	15	Populations and communities	67	13	18	2
16	15	16	Bioenergetics	64	7	26	3
17	18	17	Animal diversity	60	15	24	2
19	19	18	Plant diversity	58	12	28	2
18	22	19	Sexual reproduction of animals	57	24	18	1
22	17	20	Population genetics	55	6	36	3
23	20	21	Classification (methods)	53	20	22	5
20	26	22	Sexual reproduction of plants	53	23	24	0
21	21	23	Chemical structures (functional groups, bonding, water)	52	43	4	1
24	25	24	Cell communication (signaling and hormones)	49	5	45	2
26	24	25	Viruses	47	8	42	2
25	27	26	Nutrient cycles	46	26	24	4
27	23	27	Biotechnology	46	5	45	4
28	28	28	Prokaryotic diversity	42	10	45	4
29	30	29	Plant anatomy	40	18	41	1
30	33	30	Animal physiology	38	6	55	1
31	29	31	Animal anatomy	38	16	45	1
32	31	32	Protozoan diversity	36	10	46	8
33	32	33	Fungal diversity	35	10	46	9
35	34	34	Bioethics	33	3	55	10
34	35	35	Plant physiology	31	5	62	2
36	36	36	Animal development	28	8	62	2
37	39	37	Plant development	22	9	66	3
38	38	38	Behavior	22	7	60	11
39	40	39	Immunology	17	4	77	2
40	37	40	Bioinformatics (genomics, proteomics)	15	4	77	5
41	41	41	Social biology	10	5	66	18

Table 2. Topics ranked by the percentage of respondents (n = 310) who identified the topic as one that should be mastered in higher-level courses ("Higher Level"). Bold and shaded topics are those that were ranked within the top 25 as "Essential."

Topic	Higher Level (%)	Essential (%)	Topic	Higher Level (%)	Essential (%)
Cell structure (prokaryotic and eukaryotic)	1	69	**Bioenergetics**	26	64
DNA structure and replication	1	86	**Genetic recombination and mutations**	26	68
Meiosis	1	78	**Plant diversity**	28	58
Cell cycle	3	75	**Population genetics**	36	55
Respiration	3	86	Plant anatomy	41	40
Chemical structures (functional groups, bonding, water)	4	52	**Viruses**	42	47
Photosynthesis	4	85	**Cell communication (signaling and hormones)**	45	49
Mendelian genetics	4	75	**Animal anatomy**	45	38
Membranes and transport	4	86	Prokaryotic diversity	45	42
Protein synthesis	5	86	Biotechnology	45	46
Evolution (mechanisms, phylogeny)	5	89	Protozoan diversity	46	36
Enzymes	8	78	Fungal diversity	46	35
Ecosystems and conservation	13	74	Animal physiology	55	38
Sexual reproduction of animals	18	57	Bioethics	55	33
Populations and communities	18	67	Behavior	60	22
Speciation	19	73	Plant physiology	62	31
Classification (methods)	22	53	Animal development	62	28
Animal diversity	24	60	Plant development	66	22
Nutrient cycles	24	46	Social biology	66	10
Sexual reproduction of plants	24	53	Bioinformatics (genomics, proteomics)	77	15

understanding of science as a way of knowing, and using light microscopes, as ones that students should have before taking the college course. The highest-ranked "Essential" skills were scientific methodology, experimental design, sterile technique, pipetting, and electrophoresis. The lowest-ranked skills in the "Prior Knowledge" category were electrophoresis, polymerase chain reaction (PCR), and plant dissection. Plant dissection, chromatography, and PCR were in the lowest ranking of the "Essential" category. Overall, this preliminary survey indicated agreement on skills that should be mastered by the end of the first-year college biology course sequence.

The results of the preliminary survey and suggestions by the respondents were used to compile a list of 21 skills for the online survey. In this new survey, respondents selected skills that they believed should be developed in a year-long introductory biology course sequence for majors. The "Prior Knowledge" category was eliminated. An unlimited number of skills could be selected. It is interesting to note that the seven skills that received the highest selections were the same for both the 2Y and 4Y respondents (Figure 2). These were experimental design (4Y = 90%, 2Y = 95%), use of light microscope (4Y = 90%, 2Y = 94%), scientific methodology (4Y = 89%, 2Y = 89%), making observations (4Y = 86%, 2Y = 88%), data analysis including basic statistics (4Y = 86%, 2Y = 88%), graph construction (4Y = 87%, 2Y = 81%), and science as a way of knowing (4Y = 81%, 2Y = 86%). No obvious differences were found among these seven selected skills.

No apparent difference was found in the six skills least frequently chosen by the 2Y and 4Y respondents in the online survey (Figure 2). These included animal dissection (4Y = 47%, 2Y = 53%), use of spectrophotometer (4Y = 49%, 2Y = 45%), PCR and DNA technology (4Y = 41%, 2Y = 46%), serial dilutions and standard curves (4Y = 42%, 2Y = 41%), chromatography (4Y = 39%, 2Y = 45%), and plant dissection (4Y = 39%, 2Y = 46%). These results are very similar to those of the preliminary survey with the college faculty at the 2008 AP Readings. All seven highest-selected skills in the online survey were found in the highest eight selected in the preliminary survey. Of the six lowest-selected skills in the online survey, three ranked lowest in the preliminary survey; these were plant dissection, chromatography, and PCR.

General Comments

Fifty-nine (4Y = 40, 2Y = 19) of the survey respondents chose to provide comments about the survey or goals of the project. While the most common comment was that a consensus on what should be taught in introductory biology is "desperately" needed, others identified difficulties with the survey. The two most commonly expressed concerns were determination of the level of depth and assumptions about student preparedness.

Some respondents found identification of topics as essential difficult because, while they felt that some topics need to be covered in depth, others should be included in the course sequence as an introduction to be built upon in later courses. One colleague suggested that the addition of a category such as "introduce but don't expect to completely master" might help in this regard. Another colleague stated that "topics should be introduced in high school, further uncovered in introductory biology, and very finely studied in upper-level courses."

The second major concern expressed by respondents was related to student preparedness. These comments questioned the wisdom of

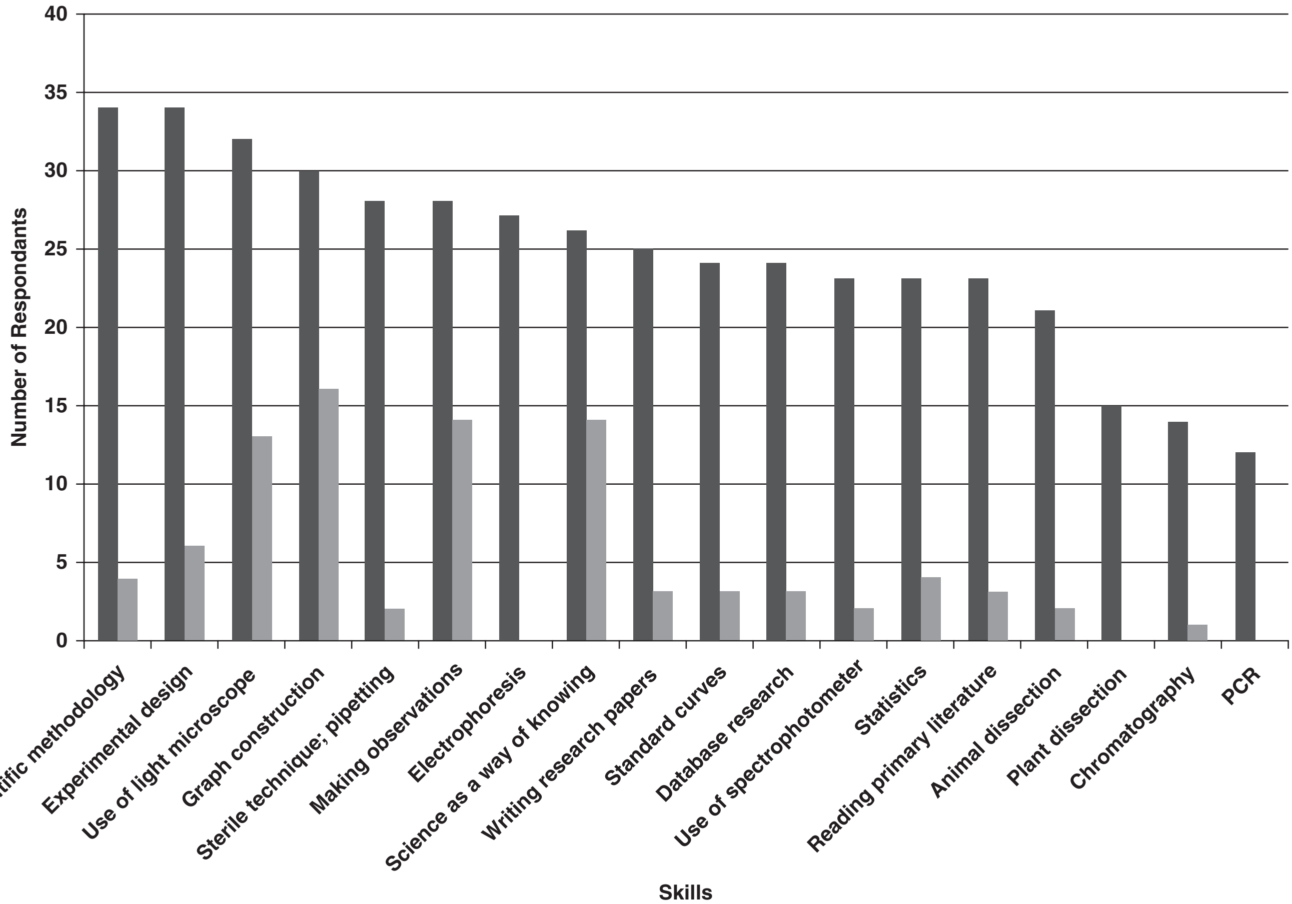

Figure 1. Skills identified as "Essential" (dark bars) and "Prior Knowledge" (light bars) by self-selected college faculty (n=54) attending the 2008 AP Biology Reading.

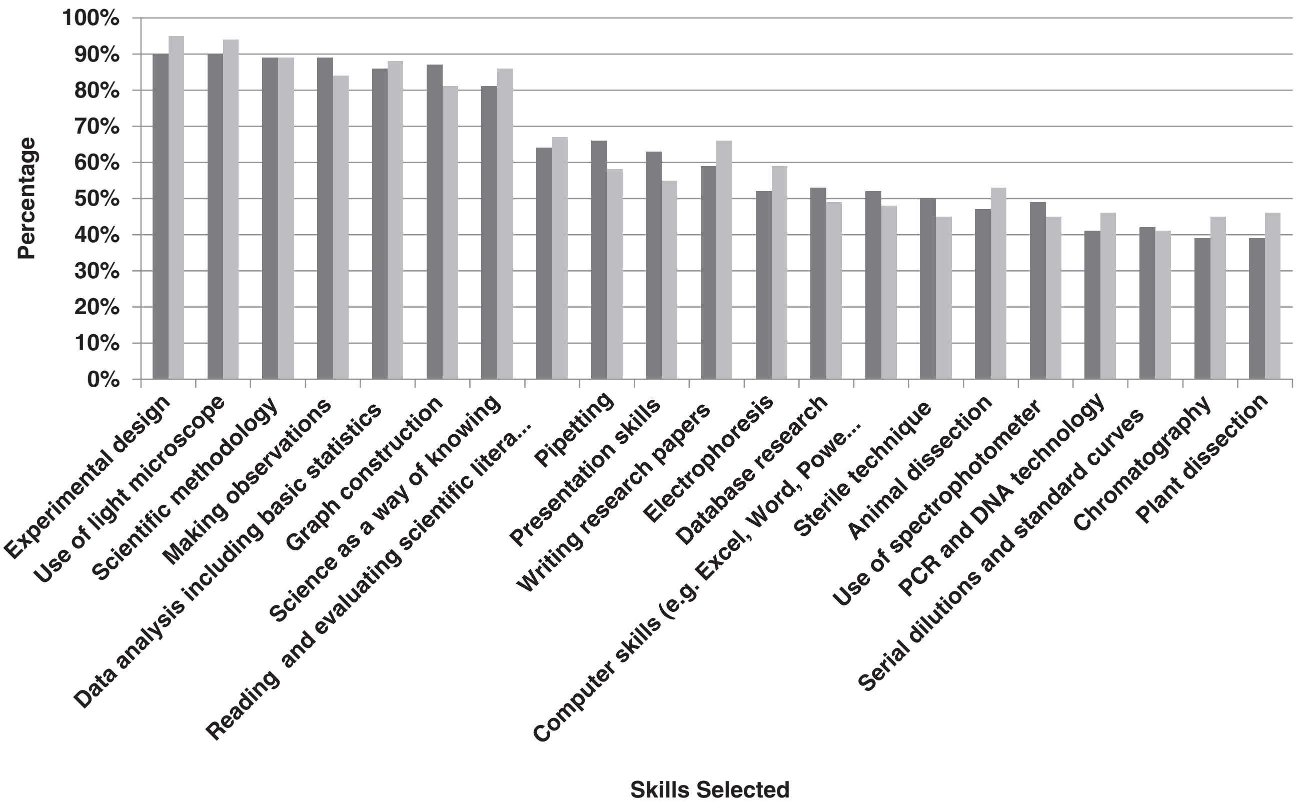

Figure 2. A comparison of Two-Year College Section (n=83; light bars) and Four-Year College and University Section (n=227; dark bars) survey respondents for skills.

making assumptions about what students learned in high school. A great number of faculty felt that students had not mastered basic high school biology concepts such as mitosis. Several individuals identified basic reading skills, mathematics, and chemistry as specific examples where student background knowledge was weak, and identified basic chemistry and functional groups as examples of topics that should have been taught in high school but had to be covered in college because the students were not able to transfer the material.

Some respondents would have liked some of the 41 listed topics to be grouped, while others wanted them separated into even smaller units. Two colleagues specifically mentioned that evolution should not be separated as a topic but should be infused throughout the curriculum; this is likely reflected in the 1% of respondents who categorized evolution as "Not Essential." Interestingly, one colleague suggested that college faculty should agree on themes rather than topics; and another comment explained that thematic organization was the basis of the AP Biology revisions.

○ Discussion

This study began as a discussion of the topics that should be taught in a year-long introductory biology course sequence for majors, with the hope that a national consensus could be reached. The goal was not to limit what topics to teach in these classes but rather to define the minimal knowledge and skills that students completing this course sequence should have attained. The aim of this project is not to dictate how this introductory course sequence should be taught, but it is hoped that by relieving pressure to "cover it all," faculty will utilize active-learning strategies, scientific investigations, and inquiry exercises, which have been proven to increase student interest and understanding (Smith et al., 2005; McDaniel et al., 2007; Morse & Jutras, 2008).

Defining a common core of topics for introductory biology is not easy. One respondent commented that "we tend to cram too much into intro courses…but it is hard to select what is really most important." The authors believe that the value of establishing a common minimal set of topics outweighs difficulties inherent in this task. While some faculty members are reluctant to remove material, others believe that only through reduction of course material can we truly help students develop the background knowledge and skills necessary for advanced coursework in biology. One survey comment stated this as "Less can be more. Effective teaching is far more important than covering the forest."

Also, while it may appear that agreement on the minimal material covered in introductory biology cannot be achieved given the state of K–12 science education, it can be countered that if high school teachers knew which topics to focus on they could better prepare students for college biology. The majority of the top 25 topics categorized as "Essential" in this study are conceptual and apply to organisms in different domains and kingdoms. These include, but are not limited to, cellular functions such as DNA replication, protein synthesis, photosynthesis, respiration, meiosis, Mendelian genetics, cell cycle, enzymes, and cell structure (prokaryotic and eukaryotic). Also represented are topics related to the diversity of life, including animal diversity, plant diversity, populations and communities, and ecosystems and conservation. These areas seem well suited to a biology major's introductory course sequence and appear to be viewed as an important part of the knowledge platform upon which students can build in higher-level courses. One respondent stated that "It is also important to note that bio majors may have been exposed to these topics prior to college, but that does not indicate their retention or mastery of the material." This reinforces the idea that critical knowledge areas required for higher-level biology courses should be included in the introductory course sequence to better ensure student preparation for higher-level courses, regardless of high school level coverage.

Overall, the results presented here indicate that the majority of respondents strongly agreed on seven basic skills needed by students who have completed an introductory college course sequence. The least important skills for students to master are plant dissection, chromatography, and PCR techniques. Interestingly, at least 50% of respondents thought that reading and evaluating scientific literature, presentation skills, writing research papers, database research, and computer skills (Excel, Word, PowerPoint) are important. This seems to indicate that researching, evaluating, and communicating biological knowledge are important skills for students even in the beginning of their collegiate biological experiences.

Given the high level of agreement among faculty at four-year and two-year institutions, the authors believe that it is feasible to identify topics that should, at minimum, be taught in an introductory course sequence for biology majors. We propose that the top 20 topics identified as "Essential" in this study be included in all introductory college course sequences for biology majors. The next five topics identified in this study as "Essential" should be considered highly recommended for inclusion, and the remaining 16 topics should be considered optional. Additionally, the authors recommend the inclusion of activities that foster the development of seven basic skills. The depth of study into these topics should always be up to the discretion of the individual instructor. These topics are the minimal set that should be included, and should in no way restrict a faculty member from teaching additional topics, either from this list or elsewhere, as they see fit for their institution's needs and to reflect their own passions.

References

American Chemical Society. (2008). ACS guidelines and supplements. [Online.] Available at http://portal.acs.org/portal/acs/corg/content?_nfpb =true&_pageLabel =PP_SUPERARTICLE&node_id =1584&use_sec =false&sec_url_var =region1&__uuid =880b3604-31f6-435d-ae5c-b1ac7ba88d39.

Cheesman, K., French, D., Cheesman, I., Swails, N. & Thomas, J. (2007). Is there any common curriculum for undergraduate biology majors in the 21st century? *BioScience*, *57*, 516–522.

Committee on Undergraduate Biology Education. (2003). *Bio 2010: Transforming Undergraduate Education for Future Research Biologists*. Washington, DC: National Academies Press.

Cooper, S., Hanmer, D. & Cerbin, B. (2006). Problem-solving modules in large introductory biology lectures enhance student learning. *American Biology Teacher*, *68*, 524–529.

Labov, J.B. (2004). From the National Academies: the challenges and opportunities for improving undergraduate science education through introductory courses. *Cell Biology Education*, *3*, 212–214.

McDaniel, C.N., Lister, B.C., Hanna, M.H. & Roy, H. (2007). Increased learning observed in redesigned introductory biology course that employed Web-enhanced, interactive pedagogy. *CBE-Life Sciences Education*, *6*, 243–249

Morse, D. & Jutras, F. (2008). Implementing concept-based learning in a large undergraduate classroom. *CBE – Life Science Education*, *7*, 243–253.

Regassa, L.B. & Morrison-Shetlar, A.I. (2007). Designing and implementing a hands-on, inquiry-based molecular biology course. *Journal of College Science Teaching*, 36, 36–41.

Smith, A.C., Stewart, R., Shields, P., Hayes-Klosteridis, J., Robinson, P. & Yuan, R. (2005). Introductory biology courses: a framework to support active learning in large enrollment introductory science courses. *Cell Biology Education*, *4*, 143–156.

Timmerman, B.E., Strickland, D.C. & Carstensen, S.M. (2008). Curricular reform and inquiry teaching in biology: where are our efforts most fruitfully invested? *Integrative and Comparative Biology*, *48*, 226–240.

Wood, W.B. (2009). Revising the AP Biology curriculum. *Science*, ***325***, 1627–1628.

EILEEN GREGORY is Professor of Biology at Rollins College, 1000 Holt Avenue, Winter Park, FL 32789-4499; e-mail: egregory@rollins.edu. JANE P. ELLIS is Professor of Biology at Presbyterian College, 503 South Broad Street, Clinton, SC 29325; e-mail: jellis@presby.edu. AMANDA N. ORENSTEIN is Assistant Professor of Biology at Centenary College, 400 Jefferson Street, Hackettstown, NJ 07840; e-mail: orensteina@centenarycollege.edu.