

Article

The Use of a Knowledge Survey as an Indicator of Student Learning in an Introductory Biology Course

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A knowledge survey (KS) is a series of content-based questions sequenced in order of presentation during a course. Students do not answer the questions; rather, they rank their confidence in their ability to answer each question. A 304-question KS was designed and implemented for a multisection, multi-instructor introductory biology course to determine whether this tool could be used to assess student learning. The KS was administered during the first 2 wk and the last 2 wk of the semester online via WebCT. Results were scored using one point for each “not confident” response (level 1), two points for each “possibly confident” response (level 2), and three points for each “confident” response (level 3). We found that scores increased significantly between the pre- and post-KS, indicating that student confidence in their knowledge of the course material increased over the semester. However, the correlation between student confidence and final grades was negligible or low, and chi-square tests show that KS scores and matched exam questions were not significantly related. We conclude that under the conditions implemented in our study, the KS does not reliably measure student learning as measured by final grades or exam questions.

Keywords: knowledge survey, self-efficacy, student learning

INTRODUCTION

Education specialists and school psychologists have recognized the value of student confidence in predicting academic performance for more than 25 yr. Self-efficacy, as described by Bandura (1977), is a student’s confidence in his or her ability to perform a task. Several reports indicate that students’ confidence in their capacity to successfully complete coursework required for a degree program are correlated with higher grades and persistence in the career path (Besterfield-Sacre *et al.*, 1998; Lent *et al.*, 1984, 1987; Multon *et al.*, 1991). Recently, Nuhfer and Knipp developed an instructional tool they call a knowledge survey (KS), which is based on these self-efficacy concepts (Nuhfer, 1996; Nuhfer and Knipp, 2003). They report that KS results represent changes in students’ learning. The purpose of our study was to evaluate how closely students’ performance track with their confidence in their knowledge of the course material.

A KS is a series of content-based questions that are sequenced in the order in which the topics are presented during the course. Students do not actually answer the questions; instead, they are instructed to read each question and rank their confidence in their ability to answer each question using a scale such as the following:

1. I am confident that I do not know the answer to this question.
2. I know at least 50% of the answer to this question.
3. I am confident that I know the answer to this question.

Students rank their confidence levels at the beginning of the semester and then repeat the same survey at the end of the semester. The instructor can compare the pre- and post-KS confidence levels and make a number of inferences about the instructional experience.

Nuhfer and Knipp (2003) describe several benefits in the use of a KS at many levels of course delivery, for both the students and the instructor. For students, a KS can provide a “road map” for the course that describes what will be expected in both content and level of rigor. It can also

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provide a sequenced study guide for the entire course that can be used to prepare for each lecture, track their understanding of the material as the semester progresses, and direct their exam preparation. Nuhfer and Knipp (2003) suggest that the repeated reviewing of the survey questions (e.g., at the beginning of the semester, at the end of the semester, and during the course) should enhance student learning. At the curriculum planning level, Nuhfer and Knipp (2003) propose that a KS can be used as an important mechanism for identifying a common set of instructional goals for multisection and multi-instructor courses, such as introductory and general education goal courses. KS results can also inform instructors of succeeding courses so that decisions can be made concerning content overlap and new content. For the individual instructor, designing a KS before the semester begins forces him or her to organize content and plan activities prior to the typically frantic start of the academic year, resulting in better course preparation. Finally, Nuhfer (1996) and Nuhfer and Knipp (2003) suggest that comparison of pre- and post-KS scores is a more comprehensive evaluation of student learning because exams can assess only a portion of the course content. In addition, a KS is a more time-efficient measure of learning for both students and instructors, and is a better assessment of student learning than traditional summative student evaluations.

Research on the ability of self-efficacy measures to predict academic performance suggests various interpretations that, taken together, indicate that student confidence does not have significant explanatory power. For example, although Lent *et al.* (1987) and Seigel *et al.* (1985) found significant, positive influence of self-efficacy beliefs on academic performance in college students, Tracey *et al.* (1997) reported weak correlation between the self-efficacy beliefs of physicians and their actual knowledge. Meta-analyses by Mabe and West (1982) and Multon *et al.* (1991) showed that the predictive abilities of self-efficacy beliefs were heterogeneous and depended on several variables present in the student populations and the testing conditions. The reflective judgment model developed by King and Kitchener (1994) suggests that students' abilities to recognize knowledge and make judgments about it develop over time. In addition, the developmental stage, during which the most changes in their evaluative abilities occur, is the transition from childhood to adulthood (i.e., the traditional college years). In light of this mixed history, it is imperative to know whether student confidence as reported in KS results compares well with actual knowledge gained.

At Idaho State University (ISU), the first semester course of the introductory biology sequence, Biology I, is a good candidate for evaluating the effectiveness and proposed benefits of a KS. The content of this survey course is diverse and includes topics such as the structure of biological macromolecules, cell structure, metabolism and energetics, cell division and reproduction, genetics, molecular biology, evolution, and ecology. The enrollment in Biology I is about 800 students per year and the number of sections varies per semester from two to six, as does the number of instructors. For example, during the 2003/2004 academic year, five different instructors taught Biology I. This course fulfills a life sciences general education goal and is a prerequisite course for several health sciences programs on our campus such as nursing, dental hygiene, pharmacy, and radiographic sciences. It is also a required course for all biology majors,

who number about 120 students per year. As such, students in Biology I enter with a range of prior knowledge of the biological sciences.

Because Biology I serves many diverse constituents, it is essential that the content presented be somewhat standardized across sections. However, even if the material covered is consistent across sections and instructors, there has been no standard method for evaluating the evenness of instruction or the degree of student learning. For these reasons, we designed a KS for Biology I consisting of about 300 questions specific for each subdiscipline of the course. During the fall 2003 semester, three Biology I instructors involving five different sections agreed to use the KS questions as a guide for preparing lectures, classroom activities, and homework assignments. Furthermore, all three agreed to require their students to complete both the pre- and post-KS.

In implementing a KS for Biology I, we attempted to address three issues in the use of KS related to student learning. First, do the students' confidence levels as measured in the pre- and post-KS increase by the end of the course? Second, can we correlate students' confidence levels with their final grades? Third, is there a relationship between students' confidence levels and their performance on exams? We believe that our results provide an important contribution to the limited literature on the utilization of this new instructional tool.

METHODS

Biology I

During the fall 2003 semester, six sections of Biology I were offered at ISU. Three instructors teaching five of these sections volunteered to utilize a KS in their course. All five sections used a common syllabus and lecture schedule; however, due to differences in the frequency of class meetings (e.g., once per week, twice per week, three times per week), presentation of course materials was not necessarily synchronized, nor was the delivery of exams. In all sections, multiple assessments contributed to the overall course grade. These included exams consisting of multiple choice and essay-format questions (~70% of the course grade), homework assignments (~13%), and weekly multiple-choice quizzes and in-class group activities (~15%). Points received for completing both the pre- and post-KS contributed about 2% to the final course grade. Homework assignments and in-class group assignments were similar or identical across all sections. Each instructor wrote his or her own exams and quizzes, but the format across all five sections was identical: exams consisted of 90% multiple-choice questions and 10% essay-format questions; weekly quizzes consisted of five multiple-choice questions worth two points each. Across these five sections, approximately 450 students completed the course and received a final grade. Class section size ranged from 23 to 169 students. However, some students chose not to complete both the pre- and post-KS, so not all of the students who completed the course were included in this study.

Knowledge Survey Design

We developed the KS for Biology I on the basis of an agreed set of course objectives and the material covered in lecture.

We selected essay-style questions because that format allowed us to represent the greatest amount of course content. The sequence of items followed the sequence in which the course material was presented. Questions used were designed to align with the various levels of Bloom's Taxonomy of Learning Objectives (Anderson and Krathwohl, 2001; Bloom *et al.*, 1956), and the relative distribution of the KS questions into the different cognitive levels was designed to mimic that found in the lecture exams. The KS contained 304 questions that were predominantly in the Knowledge level (56%) and the Comprehension and Application level (22%) (Table 1). A copy of the KS questions is included in the Appendix.

Delivery of the Knowledge Survey

The pre-KS was made available to students over a 2-wk period at the beginning of the semester online via WebCT, the course management software used at ISU. The purpose of the pre-KS and how the students were expected to use it throughout the semester were explained in class. For example, we stressed that the KS was not an exam and that we did not expect the students to know all of the answers (at least for the pre-KS). We suggested that the students use the KS as a "road map" for the course and to use it as a study guide throughout the semester. The post-KS was made available online during the last 2 wk of the semester, prior to final exams.

Technical instructions for completing the survey online were provided within WebCT. The instructions included an estimate for how much time they should expect to spend (approximately 1 h) and the step-by-step directions for using WebCT's evaluation tool. Students were given points (totaling less than 2% of their final grade) for completing both the pre- and post-KS. Because of the number of questions involved and the tedium of reading online, a printable version of the KS was made available, and students were encouraged to print it prior to recording their answers online. Furthermore, students were permitted to open and close the survey as many times as necessary before submitting it for scoring.

As is the practice with the KS, students were not required to provide an exact answer for the questions. Rather, for each question, the same three descriptors were used:

- Mark an "A" as response to the question if you don't know the answer or are not confident you could find the information to answer it completely.

- Mark a "B" as response to the question if you can truly answer at least 50% of it or know precisely where you could quickly (30 min or less) get the information.
- Mark a "C" as response to the question if you feel confident that you could answer the question completely for test purposes.

We used the same set of questions and descriptors at the beginning of the semester (pre-KS) and at the end of the semester (post-KS) prior to the final exam.

Scoring of the Knowledge Survey

Although the KS was not graded per se, each KS was scored (scores were not released to the students) using one point for each "A" response (level 1), two points for each "B" response (level 2), and three points for each "C" response (level 3). Hence, the higher the score, the greater the overall level of confidence the student had in his or her ability to answer the KS questions. Because there were 304 questions, the maximum score attainable was 912, which would indicate that a student was highly confident in his or her ability to answer all of the questions. The minimum score possible was 304, which would indicate a complete lack of confidence in the student's ability to answer any of the questions.

Analysis of the Knowledge Survey

The statistical package SPSS was used for the analysis of the KS data. First, a repeated measures analysis of variance (ANOVA) was conducted on the data to determine whether there were significant differences among pre- and post-KS scores across the five sections. Second, individual student pre- and post-KS scores were plotted against final grades in the course to determine whether there was a relationship between students' general levels of confidence (either before beginning the course or after) and their final grade. We attempted to address all of the course content through exams and various assignments. In fact, some concepts may have been evaluated in multiple formats such as multiple-choice, fill-in-the-blank, and essay questions. Therefore, the comparisons between KS results and final grades provided an overall evaluation of how closely confidence levels matched the entire course content. Third, in two of the Biology I sections, Sections 1 and 5, multiple-choice questions on the final exam were matched to questions in the KS based on similarity. This type of comparison allowed us to examine

Table 1. The relative distribution of questions in the Biology I KS based on Bloom's (1956) taxonomy; examples of each type of question are also shown

Bloom's level	% in KS	Sample questions
Knowledge	53.6	1) What are the five characteristics of life? 2) Describe the structure of amylose. 3) What are the definitions of dominant and recessive traits?
Comprehension and Application	22.7	1) Compare the structure of a phospholipid to that of a triacylglycerol. 2) Describe the three general types of survivorship curves, and how they relate to data in a life table. 3) Use the Hardy-Weinberg equation to calculate genotype frequencies within a population.
Analysis	18.1	1) What are the consequences of mutations in somatic cells versus germ line cells? 2) Why are reproductive isolating mechanisms important in the process of speciation?
Synthesis and Evaluation	5.6	1) Describe one thing about your life that would be different if the first law of thermodynamics was not true. 2) Using community energy budgets, explain why most food chains consist of only three or four steps.

specific course content confidence versus a specific graded exam question. Eight questions from Section 1 and 20 questions from Section 5 were included in the analysis. Based on the post-KS response by each student for each question, we determined what proportion of the class provided the correct answer to the exam-matched question at each of the three “levels of confidence” (1, 2, or 3). A chi-square test of independence was then run on each of the 28 questions to determine whether a significant relationship existed; Bonferroni corrected p values were also determined.

RESULTS

Analysis of the Knowledge Survey

Of the 450 students who completed Biology I in the five sections examined, a total of 336 students finished both the pre- and post-KS, representing approximately 75% of the students. Results from students who completed one but not both of the surveys or from those who did not receive a final grade for the course were not included. The pretests and posttests were compared using a repeated measures ANOVA. The main effect of the pre- to post-KS was significant ($F_{1,334} = 859.814, p < .001$) and the main effect based on section was not significant ($F_{4,334} = 0.689, p = .600$). However, since the interaction effect of pre- to post-KS by section was significant ($F_{4,334} = 2.444, p = .046$) the means must be compared at the section by repeated measures. Post hoc tests of interaction using a Bonferroni correction comparing the pre- to post-KS means were significant for each section.

Although there were no violations of homogeneity of variance among the five sections, the residuals were not normally distributed based on the Kolmogorov-Smirnov test with the Lilliefors correction. Therefore, the Wilcoxon signed rank test was performed for each section and the p values were adjusted using the Bonferroni method (Table 2). The results were identical to the parametric test. There was a significant increase in KS scores (confidence levels) for all five sections.

Correlation between Knowledge Survey and Final Grade

To determine whether the KS results could be used as predictors of a student’s performance in the course, we plotted pre- and post-KS scores against final grades (Figure 1). When the pre- and post-KS correlation coefficients for each section were compared, in all cases, the pre-KS correlation coefficient was smaller than the post-KS correlation coefficient. All of the correlation coefficients for the pre-KS scores, with the exception of Section 4, have a negligible relationship to final grade (Schmidt, 1979). Despite some significant correlations between the post-KS scores and final grades, the correlation coefficients, in general, were low.

Relationship between Matched Knowledge Survey Responses and Exam Performance

In two of the Biology I sections (Sections 1 and 5), 28 final exam questions were matched to questions in the KS based on similarity (Table 3). A total of eight questions with 64 student responses were included from Section 1, and 20 questions with 129 student responses from Section 5 were included. Chi-square goodness-of-fit tests were conducted separately on each of the 28 questions. Two guidelines were

Table 2. Wilcoxon signed rank results for significant differences between the pre-KS and post-KS mean scores by section; shown are uncorrected and Bonferroni corrected p values

Section number	Pre-KS mean	Post-KS mean	Wilcoxon Z-value	Uncorrected p value (1-tailed)	Bonferroni corrected p value
1	459.4	764.3	-7.202	< .001	< .001
2	482.0	728.2	-8.353	< .001	< .001
3	479.7	781.5	-3.621	< .001	< .001
4	442.0	743.9	-3.823	< .001	< .001
5	464.9	756.2	-10.059	< .001	< .001

used to ensure the best approximation possible. First, all expected counts had to be greater than one (Utts and Heckard, 2002). Second, at least 80% of the cells had to have an expected count greater than five. In the case that one or both of the guidelines did not hold for any particular matched question, the data were reduced to the point that the guidelines did hold. For example, if there were very few students who had no to low levels of confidence for a particular knowledge survey question (responded with a one or a two on the knowledge survey) these two responses were simply combined, providing one category of no to low levels of confidence. This reduction of data was necessary for 16 of the 28 matched questions. In these 16 cases, a Fisher’s exact test level of significance p value was calculated. As is described in Table 3, the large majority of matched questions were not statistically significant, with the exceptions of Question 8, which was significant at the .05 significance level and Questions 12, 13, and 24, which were significant at the .10 significance level. However, all of these questions lost their significance once the p values were Bonferroni corrected.

DISCUSSION

A KS tool was applied to a multisection, multi-instructor introductory biology course. Student confidence levels, final grades, and responses to KS-related test questions were examined in an effort to address the validity of the KS confidence levels as an accurate indicator of student learning.

We found that students’ confidence levels increased significantly over the semester in all five sections of Biology I. We would like to predict that the increase is due to the students’ experiences with the course material through the pre-KS, lecture, in-class exams, and course assignments, and that their increased level of confidence is related to knowledge gained. However, Mabe and West (1982) reported in their meta-analysis that one measurement condition that influenced the accuracy of self-evaluation tests is the amount of experience an individual had with those types of self-efficacy tests. Furthermore, King and Kitchener (1994) suggest that the development of college students’ evaluative abilities takes longer than one semester. It remains possible that some part of the increase in confidence that we see is due to a semester’s worth of experience with self-evaluation and the KS instrument itself.

The relationship of student confidence (as measured by the KS) and course performance is not well supported by our data. There is negligible correlation between confidence levels at the beginning of the course and final grade, which might be expected of freshman-level students with little

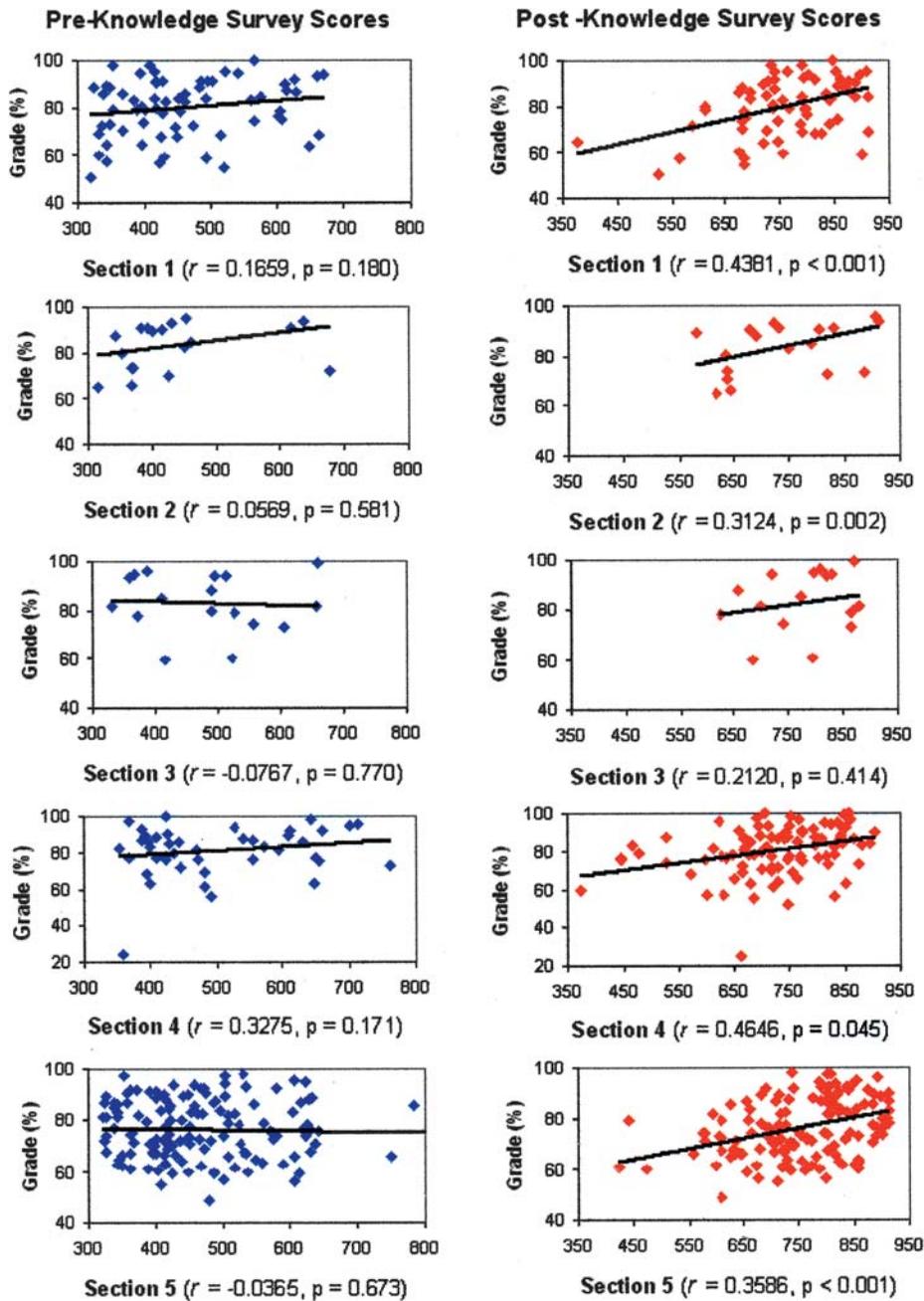


Figure 1. Plot of student final course grade (as a percentage of total possible points) against their pre-KS and post-KS scores by section. Shown are correlation and *p* values for each plot.

experience in self-evaluation. Our data suggest that students' levels of confidence at the beginning of the semester are not good predictors of achievement in the course. By the end of the course, the students' confidence with the course material increased, but the correlation of their level of confidence and their final grade is still low. Therefore, we do not find evidence that student confidence levels are a good indicator of course performance.

The relationship between student confidence levels and their performance on matched exam questions is also not

supported by our data. The uncorrected *p* values show four matched questions that are statistically significant at the .10 significance level or better. However, the Bonferroni corrected *p* values show no statistical significance for any of the 28 matched questions. Therefore, we find insufficient evidence to conclude that there is a relationship between student confidence and exam performance.

We were concerned that the ability of students to accurately estimate their level of confidence may be influenced by the cognitive level of the question. We

Table 3. Chi-square goodness-of-fit results for exam-matched KS questions (Questions 1–20 were from Section 5 and questions 21–28 were from Section 1); shown are uncorrected and Bonferroni corrected *p* values

Question topic	Chi-square	<i>df</i>	Uncorrected <i>p</i> value (2-tailed)	Bonferroni corrected <i>p</i> value
1. Ecology: succession	1.267	2	.531	1
2. Ecology: life tables	2.534	2	.282	1
3. Species: biological species concept	0.948	1	.356 ^a	1
4. Ecology: key stone species	0.484	1	.613 ^a	1
5. Ecology: competition	0.424	2	.809	1
6. Species: reproductive isolation	3.940	2	.139	1
7. Genetics: natural selection	0.073	1	.861 ^a	1
8. Genetics: Hardy-Weinberg principle	4.953	1	.034 ^a	0.729
9. Genetics: fitness	2.654	1	.110 ^a	1
10. Ecology: species interactions	2.362	1	.162 ^a	1
11. Evolution: homologous structures	3.153	2	.207	1
12. Ecology: life histories	5.960	2	.051	1
13. Ecology: competition	5.455	2	.065	1
14. Species: allopatric speciation	4.267	2	.118	1
15. Genetics: natural selection	3.443	2	.179	1
16. Ecology: life tables	3.462	2	.177	1
17. Species: reproductive isolation	0.075	2	.963	1
18. Evolution: Lamarck versus Darwin	0.000	1	1.000 ^a	1
19. Ecology: life tables	0.355	2	.838	1
20. Genetics: Hardy-Weinberg principle	0.077	1	.848 ^a	1
21. Evolution: descent with modification	1.844	1	.265 ^a	1
22. Evolution: macroevolution	3.139	1	.128 ^a	1
23. Species: biological species concept	0.466	1	.589 ^a	1
24. Species: allopatric speciation	4.156	1	.058 ^a	1
25. Evolution: homologous structures	0.016	1	1.000 ^a	1
26. Species: reproductive isolating mechanisms	1.746	1	.207 ^a	1
27. Populations: natural selection	0.465	1	.613 ^a	1
28. Ecology: life histories	3.605	1	.078 ^a	1

^aFisher's exact test significance value provided.

speculated that some students may have a harder time evaluating their level of confidence in the higher cognitive questions (e.g., Bloom's Analysis, Synthesis, and Evaluation) compared with the lower cognitive questions. Most of the matched questions we used for the comparison were ranked at the Knowledge, Comprehension, or Application levels, except Questions 12 and 25, which we ranked at the Synthesis and Evaluation and Analysis levels, respectively. Since none of the correlations are significant, we cannot assess the influence of the cognitive level of the question on the students' ability to evaluate their confidence.

Our results differ from those of Nuhfer (1996) and Nuhfer and Knipp (2003), who report that KS confidence levels are a good representation of student knowledge. We can suggest three possible explanations. First, we could find no report of statistical analysis of their KS data. In the absence of this analysis, it is difficult to assess the strength of the relationships between KS scores and grades. In addition, they may find correlations of lower strength acceptable. Second, we found no report on the enrollment in the courses in which they reported the use of the KS. It is possible that our large sample size lent itself to a more favorable statistical analysis based on scale alone. Finally, our student populations may be different. They reported results of students from a large metropolitan area; the introductory biology course used in this study consists primarily of freshman and sophomores largely drawn from rural Idaho.

One potentially confounding variable in our study and those of Nuhfer and Knipp (2003) is the differing abilities of the students to self-evaluate their own knowledge. Students with differing levels of self-efficacy (e.g., high or low) will have corresponding abilities to self-evaluate (Zimmerman, 1989). Schunk (1996) predicts that it is necessary to teach students self-evaluation skills prior to requiring them to self-evaluate. To do this, the instructor must model the types of self-reflection questions that students need to ask themselves, such as "What are the strengths and weaknesses of my answer? Did I provide all of the details? Did I answer the question completely?" (Carr, 2002; Greenberg, 1988; Zimmerman, 1989). In addition, the instructor needs to provide regular feedback on each student's progress (Schunk, 1996). Schunk (1996) and Zimmerman (1989) predict that as students' self-evaluation skills improve, their learning will also improve. Therefore, if a KS is implemented with consistent instructor reinforcement on self-evaluation skills throughout the course, it is possible that confidence levels may more closely reflect content knowledge by the end of the semester. In addition, the students will have learned a valuable skill that they can apply in other classes.

Despite the limitations in the use of the KS as an indicator of student learning, we have anecdotal evidence that supports many of the reported benefits of a KS. For example, each instructor observed many students using the printed version of the KS as a guide to prepare for exams. With a different experimental design, it would be possible to

determine whether learning was enhanced for those students who consistently used the KS as a study guide. Also, across the five different sections (three different instructors), the pre-KS scores for each question were strikingly similar. The common high-confidence-level questions suggest that the entering students had prior exposure to some of the same course content. Finally, all three instructors used the KS as a guide for developing course content with the expectation that we would achieve content consistency across sections, a common goal for multisection, multi-instructor introductory level courses. Future research could be designed to test each of these valuable attributes of KS.

Our overall evaluation of a KS is that it can be an effective instructional tool for multisection, multi-instructor courses, such as general education or introductory courses for which a specified body of knowledge is expected to be taught. However, our data demonstrate that introductory-level students do not accurately judge their knowledge. Further research into the influence of instruction in self-evaluation skills on confidence levels may provide a mechanism to align KS confidence levels with student learning. Until further studies warrant otherwise, we cannot recommend the KS as an appropriate tool for measuring student learning.

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Appendix
Biol 101
Biology I
KNOWLEDGE SURVEY / STUDY GUIDE
Fall 2003

This is a *knowledge survey* rather than a test. It is a learning aid for you and an assessment tool for your instructor and possibly for outside reviewers. The results from this are NOT part of your graded work. In a knowledge survey, you don't actually answer the questions or solve the problems provided, but you instead evaluate the degree to which you have present knowledge to answer a question or address an item.

You MUST complete the Knowledge Survey using WebCT. However, you can read through the paper version and mark your answers ahead of time. Then return to the WebCT course, open the actual Knowledge Survey, and fill in your answers. Regardless of how you complete the Knowledge Survey, you will read each question and then indicate with either an A, a B, or a C in accord with the following instructions:

- Mark an "A" as response to the question if you feel confident that you could answer the question completely for test purposes.
- Mark a "B" as response to the question if you can truly answer at least 50% of it or know precisely where you could quickly (30 minutes or less) get the information.
- Mark a "C" as response to the question if you don't know the answer or are not confident you could find the information to answer it completely.

Keep these questions and use them as a study guide for the exams this semester. They are also a good way to monitor your increasing mastery of the material through the semester. This survey will be given again the last week of the semester. The questions are broken down by chapter.

Chapter 1, The Science of Biology

1. What are the 5 characteristics of life?
2. Describe the steps of the scientific process.
3. In a scientific experiment, what is a control?
4. What is the difference between a theory and a hypothesis?
5. Formulate a hypothesis and design an experiment to test that hypothesis.

Chapter 2, The Nature of Molecules

6. What are the characteristics of the particles that compose atoms?
7. What is the difference between atomic mass and atomic number?
8. What are isotopes and radioisotopes?
9. What are orbitals?
10. How many electrons can inhabit an orbital?
11. Why do electrons have potential energy?

12. What are energy levels and what is the valence energy level?
13. What is the octet rule?
14. Describe an example of using the potential energy of electrons to do work.
15. What are the characteristics of ionic and covalent bonds?
16. What kinds of covalent bonds can form, and how do they form?
17. Describe the structure of water.
18. How do hydrogen bonds form?
19. What are the properties of water that are due to its ability to form hydrogen bonds?
20. Understand the ionization properties of water and pH.

Chapter 3, The Chemical Building Blocks of Life

21. What are the 7 major chemical functional groups and the characteristics of each?
22. Be able to describe dehydration synthesis and hydrolysis.
23. What is the basic structure of amino acids?
24. What are the different functional properties of amino acid R groups?
25. How is a peptide bond formed?
26. What is the basic structure of a nucleic acid?
27. What are the differences between DNA and RNA?
28. How is a phosphodiester bond made?
29. What is the structure of the double helix?
30. What is the structure of a fatty acid?
31. What is the structure of triacylglycerol?
32. What is the basic structure of a sugar?
33. What is the structure of a sugar when it is dissolved in water?
34. How are disaccharides and polysaccharides made?
35. What are sugar isomers and why are they important?
36. Describe the structure of amylose.
37. How is amylose synthesized?
38. What is the function of amylose?
39. Where is amylose stored in a plant cell?
40. How is the structure of amylopectin different than amylose?
41. What is the storage form of sugar in animals called?
42. How is glycogen synthesized?
43. Compare the structure of glycogen to that of amylopectin.
44. What is the structure of cellulose?
45. Why is cellulose a good structural molecule?
46. How is the structure of chitin different than cellulose?
47. What structures are made of chitin?
48. Compare the structure of a phospholipid to that of a triacylglycerol.
49. Why is the polar head group of a phospholipid attracted to water, while the fatty acid tails are not?

50. Describe the structure of cholesterol.
51. Why is cholesterol classified as a lipid?
52. What are the six major functions of proteins?
53. In your own words, define the six levels of protein structure.
54. Describe the patterns of hydrogen bonding that make the structure of an α helix different than a β sheet.
55. What are the functions of chaperone proteins?
56. Why is it important that the pH of the different compartments of a human body remain constant?
57. Why is DNA called a double helix?
58. What are the base-pairing rules?
59. What are the chemical differences between DNA and RNA?
60. Why does the cell need two different kinds of nucleic acids?

Chapter 4, The Origin and Early History of Life

61. Describe the evidence supporting the origins of life, cells and eukaryotic cells.

Chapter 5, Cell Structure

62. What are the structures that are common to all cells?
63. What is the cell theory?
64. Why aren't cells larger?
65. What are the characteristics of bacteria?
66. How are eukaryotic cells different than bacteria?
67. Describe the structure of the nucleus including the nuclear envelope and chromosomes.
68. What are the components of the endomembrane system, and what are the functions of each component?
69. How are the endomembrane components related to each other?
70. Describe the structures and functions of mitochondria, chloroplasts and centrioles.
71. What is the theory of endosymbiosis?
72. Describe the components of the cytoskeleton and their functions.
73. Describe the structure of high speed molecular motors.
74. Compare the structures of flagella and cilia.

Chapter 6, Membranes

75. Explain how all the cell membrane components fit together in the membrane.
76. What factors control the degree of fluidity of a lipid bilayer?
77. What are the common characteristics of transmembrane proteins?
78. What are the basic secondary and tertiary protein structures that allow proteins to fit in the membrane?
79. What are 6 possible functions for transmembrane proteins?
80. Describe the two kinds of bulk passage endocytosis.
81. How is receptor-mediated endocytosis different than bulk passage endocytosis?
82. What is exocytosis?
83. What is the definition of active transport?

84. Describe how a sodium-potassium pump works.

Chapter 8, Energy and Metabolism

85. What is the difference between potential and kinetic energy?
86. List six forms of energy.
87. Into which form of energy can all the other forms be converted?
88. What is the ultimate source of energy for biological systems and how is it made available for life on earth?
89. What is the definition of kilocalorie?
90. Write the equation for any biological oxidation-reduction reaction. Explain which molecule is oxidized, which is reduced and which gains energy.
91. What is the First Law of Thermodynamics?
92. Describe one thing about your life that would be different if the first law of thermodynamics was not true.
93. Why can't cells use heat energy to do work?
94. What is the Second Law of Thermodynamics?
95. What is the mathematical definition of free energy (G)? Explain all the terms in this equation.
96. Changes in free energy occur when chemical reactions take place. How do you determine how much the free energy changes?
97. Why is it important to know the free energy change for a particular chemical reaction?
98. What is activation energy, and why is it important for biological systems?
99. What are enzymes, and why do cells need them?
100. How do temperature and pH influence the structure and functions of enzymes?
101. What is the difference between a competitive and a noncompetitive enzyme inhibitor?
102. What does it mean to say that an enzyme has different conformations?
103. What is an active site?
104. What is a substrate?
105. How do substrates bind to the active sites of enzymes?
106. What role do conformational changes play in reaction mechanisms?
107. Describe the mechanism of action of the enzyme sucrase.
108. What is the structure of ATP?
109. Why are the phosphates the key part of the ATP molecule in regards to energy storage?
110. What is the chemical reaction that cleaves ATP?
111. What are the products of the cleavage of ATP?
112. What is the definition of metabolism?
113. How do biochemical pathways work?
114. Why are cellular compartments important for biochemical pathways?
115. Why do biochemical pathways need to be regulated?
116. Explain how feedback regulation works.

Chapter 9, How Cells Harvest Energy

117. What are the two basic metabolic processes and which one releases energy from the food we eat?
118. How is the energy in the food we eat released?
119. What is cellular respiration?

120. Describe how ATP is made by substrate level phosphorylation.
121. How does a cell use the energy in ATP to power movement?
122. What are the two ways ATP hydrolysis can be coupled to endergonic reactions?
123. What are the four stages of glucose catabolism?
124. When an intermediate of glucose catabolism is oxidized, what molecules are extracted and what parts of these molecules are accepted by NAD⁺?
125. How is the glucose molecule primed and why does it need to be primed?
126. What molecule enters the energy extraction step of glycolysis?
127. What are the three reactions that extract energy during the energy extraction step of glycolysis?
128. What is the end product of glycolysis?
129. Where in the cell do the reactions of glycolysis take place?
130. What are the three things that happen during the oxidation of pyruvate, and which one of these is an energy releasing step?
131. Where in the cell does pyruvate oxidation take place?
132. What does it mean that the Krebs cycle is a cyclic pathway?
133. What molecule is necessary for the Krebs cycle to begin?
134. Where in the cell does the Krebs cycle take place?
135. How is acetyl CoA primed in the Krebs cycle?
136. What intermediate enters the energy extraction steps of the Krebs cycle?
137. How many energy extraction steps occur in the Krebs cycle, and in what form is the energy extracted at each of these steps?
138. Which steps of the Krebs cycle include the release of CO₂?
139. At the end of the Krebs cycle, what has happened to the carbon atoms from the original glucose molecule?
140. At the end of the Krebs cycle, what has happened to the energy in the glucose molecule?
141. How is the energy in NADH released, and why is it harvested in steps, rather than all at once?
142. Where is the electron transport chain located?
143. Describe the order of the components of the electron transport chain.
144. Where along the electron transport chain are H⁺ pumped out of the mitochondria matrix?
145. What molecule is the final electron acceptor, and what product is produced when it accepts electrons?
146. How is the H⁺ gradient used to synthesize ATP?
147. Which stage of glucose catabolism is the major energy producer?
148. What molecules are produced by lipid and protein oxidations and where do they fit into the catabolic pathways of glycolysis, pyruvate oxidation or the Krebs cycle?

Chapter 10, Photosynthesis

149. How is photosynthesis similar to electron transport and ATP synthesis in cellular respiration?
150. What product is made by photosynthesis that is not made by the electron transport chain?

151. What is the source of energy for photosynthesis?
152. What are the order of components in photosystems I and II?
153. Where are H⁺ ions pumped out of the stroma and into the thylakoid space?
154. Do the same electrons that traveled through photosystem II also travel through photosystem I?
155. Where is NADPH synthesized?
156. Where do the chlorophyll molecules in photosystem II get electrons to replace the electrons that are transferred during photosynthesis?
157. Why do photosynthetic organisms release oxygen gas?
158. How is ATP synthesized in chloroplasts?
159. Where do the light dependent reactions take place?
160. Describe the carbon fixation reaction.
161. Why do the light independent reactions need ATP and NADPH?
162. How do plants make glucose from glyceraldehyde 3-phosphate?

Chapter 11, How Cells Divide

163. Describe the structure of chromosomes.
164. What are histones and nucleosomes?
165. What is the difference between a haploid cell and a diploid cell?
166. What is the difference between homologous chromosomes and sister chromatids?
167. How are sister chromatids held together?
168. What happens in each of the 5 phases of the cell cycle?
169. What is the mitotic spindle composed of, and what is its function?
170. What are kinetochores?
171. Describe the movement of the chromosomes through the stages of mitosis.

Chapter 12, Sexual Reproduction and Meiosis

172. What are gametes, and what is their chromosome number (ploidy)?
173. What is the difference between somatic cells and germ line cells?
174. Describe the formation of the synaptonemal complex.
175. At which stage of meiosis does synapsis occur?
176. Describe the process of crossing over.
177. When can crossing over result in new combinations of genetic information?
178. What is a chiasma, and what is its function during meiosis?
179. At what stage of meiosis does the reduction in chromosome number occur?
180. Describe the movement of the chromosomes during meiosis.
181. What is independent assortment, and why does it generate so much diversity among offspring of sexually reproducing organisms?
182. What is random fertilization?
183. Why does random fertilization increase the amount of diversity produced by independent assortment?
184. What is the contribution of crossing over to the generation of diversity?
185. What is the significance of genetic diversity?

Chapter 13, Patterns of Inheritance

186. Describe 4 reasons why garden peas were an excellent experimental organism for Gregor Mendel.
187. Describe the technique by which Mendel carried out self-fertilization and cross-fertilization experiments.
188. How are F1 generation individuals produced?
189. What are the definitions of dominant and recessive traits?
190. How do the genotypes compare to the phenotypes of F1 individuals?
191. How are F2 generation individuals produced?
192. Compare the phenotypic ratio and genotypic ratio of the F2 individuals.
193. What is an allele?
194. What does it mean for an individual to be homozygous or heterozygous for an allele?
195. Describe the 5 points of Mendel's model of heredity.
196. Be able to use a Punnett square to predict the genotypes and phenotypes of a monohybrid cross.
197. What is the definition of Mendel's 1st law of heredity, the Law of Segregation?
198. Why do the predictions made by Punnett squares depicting monohybrid crosses demonstrate the Law of Segregation?
199. What is the difference between a monohybrid and a dihybrid cross?
200. What is the genotype of a true-breeding pea plant that has round, yellow seeds?
201. Predict the possible gamete combinations for any dihybrid cross of your choice.
202. Use a Punnett square to predict the genotypes and phenotypes of the offspring of your dihybrid cross.
203. What is the definition of Mendel's 2nd law of heredity, the Law of Independent Assortment?
204. Why do the predictions made by Punnett square analysis of dihybrid crosses demonstrate the Law of Independent Assortment?

Chapter 14, DNA: The Genetic Material

205. Describe the structure of a double helix.
206. How are the two nucleic acid strands held together?
207. What are the orientations of the two nucleic acid strands in the double helix?
208. What enzymes are required for replication of DNA, and what are the functions for each of these enzymes?
209. Describe the order in which these enzymes must function in order for a DNA molecule to be replicated.
210. Why is the leading strand replicated continuously, but the lagging strand is not?
211. What is a replication bubble, and why are there so many of them on a chromosome?
212. What is the twisting problem during replication, and how is it solved?

Chapter 15, Genes and How They Work

213. What is the central dogma of gene expression?
214. What enzyme carries out transcription?
215. What is the mechanism for transcription of RNA?

216. What is the difference between the template strand and the coding strand of DNA?
217. What is a promoter site, and what sequences are found in promoter sites?
218. What happens during the initiation, elongation and termination stages of transcription?
219. What posttranscriptional modifications are made to the RNA molecule after transcription, and what are the purposes of those modifications?
220. What is the triplet genetic code?
221. If there are only 20 amino acids, why do cells use 64 codons?
222. What are the three kinds of RNA molecules, and what are their functions?
223. Explain what happens during the initiation, elongation and termination stages of translation.
224. What are introns and exons, and where are they found on chromosomes?
225. What are snRNPs and spliceosomes, and how do they function to remove introns?
226. Why do genes have introns and exons?

Chapter 18, Altering the Genetic Message

227. What is the definition of a mutation?
228. Think of some examples of good and bad mutations.
229. What are the consequences of mutations in somatic cells versus germ line cells?
230. What are base substitutions, and how are they caused?
231. What are some potential consequences of base substitutions?

Chapter 20, Genes within Populations

232. Distinguish between evolution, microevolution, and macroevolution.
233. What is population genetics?
234. What is a gene pool, and how do biologists measure a gene pool?
235. What are the defining features and characteristics of the five microevolutionary forces?
236. How do each of the five microevolutionary forces drive microevolution?
237. What is the Hardy-Weinberg principle, and why is it useful?
238. What are the assumptions of the Hardy-Weinberg principle?
239. Given the frequency of genotypes in a population, calculate allele frequency, observed genotype frequency, expected genotype frequency (under Hardy-Weinberg Equilibrium), and determine whether the population conforms to the Hardy-Weinberg model.
240. Describe three types of natural selection.
241. Quantitatively demonstrate the effect of natural selection on the genetic make-up of a population of your choice.
242. What is fitness in an evolutionary sense?
243. Why is the allele causing sickle-cell anemia so common in Africans?
244. How does the presence of the sickle-cell allele in Africans demonstrate heterozygote advantage?

- 245. How does the research of Peter and Rosemary Grant illustrate the ability of selection to cause microevolutionary change?
- 246. How does the peppered moth example illustrate microevolution?

Chapter 21, The Evidence for Evolution

- 247. Describe two macroevolutionary patterns?
- 248. Describe two examples of descent with modification?
- 249. What is the connection between micro and macroevolution?
- 250. Compare Lamarck's and Darwin's mechanisms for evolution.
- 251. What observations and inferences lead Darwin to the idea of natural selection?
- 252. How does the research of Peter and Rosemary Grant illustrate and support Darwin's ideas about natural selection?
- 253. What is the theory of evolution?
- 254. What phenomena does the theory of evolution bring together that would otherwise have no common explanation?
- 255. Distinguish between homologous and analogous structures and give examples of each.
- 256. How do homologies illustrate the principle that evolution makes new structures out of pre-existing structures?
- 257. How do poorly "designed" structures illustrate historical constraints on natural selection?

Chapter 22, The Origin of Species

- 258. What is the Biological Species Concept?
- 259. What are some problems with the way this concept defines a species?
- 260. Describe prezygotic and postzygotic reproductive isolating mechanisms, and explain how they are important in the process of speciation.
- 261. What is allopatric speciation, and how can it lead to the formation of a new species?
- 262. What conditions favor allopatric speciation?
- 263. What is sympatric speciation?
- 264. How could polyploidy result in speciation?
- 265. What is an adaptive radiation?
- 266. How does the speciation of Darwin's finches illustrate an adaptive radiation?

Chapter 24, Population Ecology

- 267. Define ecology and population.
- 268. What characteristics of a population influence population growth?
- 269. How are some of the population characteristics used in a life table?
- 270. Be able to calculate and interpret data in a life table.
- 271. What is a cohort?
- 272. What are the three general types of survivorship curves, and how do they relate to data in a life table?
- 273. What is the net reproductive rate (net replacement rate)?
- 274. How is net reproductive rate calculated, and what does it tell you about changes in population size?

- 275. What do age-structure diagrams tell you about population growth?
- 276. What are two models of population growth?
- 277. Describe human population growth in terms of these models.
- 278. What are density dependent and density independent factors that influence population growth, and how do these factors influence population growth?
- 279. Compare two life-history strategies.

Chapter 25, Community Ecology

- 280. What are five kinds of interactions that occur between species, and how do they affect the species involved?
- 281. What is the difference between habitat and niche?
- 282. What is the difference between fundamental niche and realized niche?
- 283. Describe two kinds of competition, the cause of competition, and three outcomes of competition.
- 284. Use Darwin's finches to illustrate how resource partitioning (and character displacement) occur.
- 285. Describe community structure, and explain how competition and predation affect community structure.
- 286. Give an example of an evolutionary arms race.
- 287. What are two outcomes of predation?
- 288. What is a keystone species? Give an example.
- 289. Distinguish between the two types of succession.
- 290. What is one model of how succession occurs?
- 291. What is the relationship between the number of species present and area, and how does this relationship impact species conservation?

Chapter 28, Dynamics of Ecosystems

- 292. Explain why nutrients cycle but energy flows.
- 293. What are the major stores of water and the processes that transfer water from one store to another?
- 294. What drives the hydrologic cycle?
- 295. What is the importance of vegetation to the hydrologic cycle of tropical rainforests?
- 296. What are the major stores of carbon, and what processes transfer carbon between stores?
- 297. How does the concentration of atmospheric carbon dioxide change over the course of a year, and why does it change?
- 298. What are the major stores of nitrogen and the processes that transfer nitrogen between stores?
- 299. How do salmon influence nutrient cycles in the Pacific Northwest?
- 300. What are the major trophic levels in a food web?
- 301. What happens to energy as it flows through a food web?
- 302. How do disruptions to one part of a food web impact the entire food web?

Chapter 29, The Biosphere

- 303. What are the two most important factors contributing to the distribution of the major biomes of the world?
- 304. What are the major biomes of the world and where are they located?