**Introduction**

There is general agreement that scientific literacy in biology should include both information about specific topics and an understanding the process by which this information is obtained. The Vision and Change in Undergraduate Biology Education document produced by the American Association for the Advancement of Science (AAAS) identified the key concepts that students need to understand as well as the set of competencies they need to acquire (AAAS 2009; Woodin et al. 2010). The competencies include the ability to apply the process of science, the ability to use quantitative reasoning, and the ability to use modeling and simulation. Since the publication of this proposal, instructors of a variety of different courses have developed strategies for doing this that go beyond the standard textbooks, class lectures, and laboratory exercises. These include the careful analysis of graphs (Pechenik and Tashiro 1992; Malamitsa et al. 2008), the reading of news stories and related journal articles (Krontiris-Litowitz 2013; Moisander 2021), the use of course based undergraduate research experiences or CUREs (Bennett et al. 2021; Sun et al. 2022), and extended undergraduate research programs such as SEA-PHAGES (Jordan et al. 2014). These approaches have been linked to Bloom’s taxonomy of learning where students move from the acquisition of basic knowledge and comprehension to application and analysis and finally on to evaluation and synthesis (Bloom et al. 1956).

 While the goals of undergraduate education have changed, most textbooks have not. Although those in the area of Genetics normally include data analysis problems as the end of each chapter, only a few of those in the areas of Biochemistry, Cell Biology, and Ecology do so. This is particularly a problem in the case of Microbiology, where the primary target audience for textbooks is students in allied health fields such as nursing. The acquisition of basic information and demonstrating its relevance to human disease are the primary goals of the course, not the scientific process. Even the more advanced textbooks for biology or microbiology majors such as those by Willey et al. (2022), Wessner et al. (2021), Madigan et al. (2017), and Slonczewski et al. (2020) contain very little material on this process.

In 1997, I published a paper entitled “Using data analysis problems in a large general microbiology course” in The American Biology Teacher (Deutch 1997). This was based on my experience in using these problems at the University of Nevada, Las Vegas. A copy of the PDF of this paper included in the Content folder. This paper described the organization of my course, the structure of the data analysis problems, and the use and student response to these problems. Each problem was based on a single journal article and included five multiple-choice questions. The multiple-choice questions were of three basic types: type A questions were those that asked students to recall basic terms or concepts related to the problem; type B questions were those that asked students to read a table or figure of data; and type C questions were those that asked students to draw conclusions from the data, to make predictions, or integrate the material with other information presented in the course. The paper included three examples dealing with microbial structure, microbial metabolism, and microbial pathogenesis.

The purpose of this project is to provide additional examples of these data-analysis problems and to set up a mechanism by which other instructors might use them or contribute new problems appropriate to their courses and areas of interest. Twelve new problems are provided in the Content folder, with more to follow. The examples fall into six general areas: Microbial Structure, Microbial Growth, Microbial Metabolism, Microbial Genetics, Microbial Ecology, and Microbial Pathogenesis. However, some problems utilize concepts from several areas. New areas such as Virology and Microbial Biotechnology could be added later if there is sufficient interest. The current examples in each area were written by Charles E. Deutch and include one problem taken from an older set written in the 1990s and one new problem based on journal articles published from 2010 to 2020. Most have five multiple-choice questions but some have more. Again each problem includes questions of the A type, B type, and C type.

The problems are written in Microsoft Word so other instructors can modify them as necessary to meet the needs of students in their courses. The problems may be used as part of problem sets or homework assignments, discussion boards, or examinations. I have found that in-class discussions with groups of students work best, but other instructors may use them in different ways. The answers to the multiple-choice questions are not given in order to encourage careful reading of the text and analysis of the data, although most instructors should be able to figure them out quickly. The bibliographic citation for the journal article on which each problem is based is included, so instructors or students can follow up on that issue.

Instructors of other courses in Microbiology are encouraged to create similar problems based on their personal areas of interest and those of the students in their courses and to upload them into the Project site. For simplicity, it would be best everyone uses the same basic format in which the file name for the problem includes the name of the microbe involves and brief key work to the topic (for example: MDP Campylobacter fetus S layer.docx). Each problem should also include a heading with the general area of microbiology involved, the name of the microorganism, and the full bibliographic listing for the journal article on which it is based including the DOI number if possible. Please look at the current files as examples. If you are willing to do so, also give your name and affiliation, the date when the problem was written, and your contact information at the end.

**References**

American Association for the Advancement of Science (AAAS) Conference Homepage. 2009. Vision and Change in Undergraduate Biology Education: A View for the 21st Century. Available at https://www.aps.org/programs/education/undergrad/upload/Revised-Vision-and-Change-Final-Report.pdf

Bennett, K. F., Arriola, P. E., Marsh, T. L., Mineo P. M., Raimondi, S. L, and Shaffer, C. L. 2021. CURE in a box: an online CURE for introductory biology majors that incorporates *Vision and Change*. Journal of Microbiology & Biology Education 22(1): 22.1.20.

 doi: 10.1128/jmbe.v22i1.2325.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H. and Krathwohl, D. R. 1956. Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive domain. David McKay Company.

Deutch, C. E. 1997. Using data analysis problems in a large general microbiology course. The American Biology Teacher 59: 396-402.

Jordan T. C., Burnett, S. H., Carson, S., Caruso, S. M., Chase, K., DeJong, R. J. et al. 2014. A broadly implementable research course in phage discovery and genomics for first-year undergraduate students. Mbio 5(1): e0151-13. doi: 10.1128/mBio.01051-13.

Krontiris-Litowitz, J. 2013. Using primary literature to teach science literacy to introductory biology students. Journal of Microbiology & Biology Education 14: 66-77. doi: 10.1128/jmbe.v14i1.538

Madigan, M., Bender, K., Buckley, D., Sattley, W., and Stahl, D. 2017. Brock Biology of Microorganisms, 15th edition. Pearson.

Malamitsa, K., Kokkotas, P., and Kasoutas, M. 2008. Graph/chart interpretation and reading comprehension as critical thinking skills. Science Education International 19: 371-384.

Moisander P. H. 2021. Practicing critical thinking in undergraduate microbiology classes by presenting news stories with data evidence. Journal of Microbiology & Biology Education 22: e00171-21. doi: 10.1128/jmbe.00171-21.

Pechenik, J. A., and Tashiro, J. A. 1992. The graphing detective: an exercise in critical reading, experimental design & data analysis. The American Biology Teacher 54: 432-435.

Slonczewski, J. L., Foster, J. W., and Zinser, E. R. 2020. Microbiology: an evolving science, fifth edition. W. W. Norton & Company.

Sun E., König, S. G., Cirstea, M, Hallam, S. J., Graves, M. L., and Oliver, D. C. 2022. Development of a data science CURE in microbiology using publicly available microbiome data sets. Frontiers in Microbiology 13:1018237. doi:10.3389/fmicb.2022.101823

Wessner, D., Dupont, C., Charles, T., and Neufeld, J. 2021. Microbiology, third edition. Wiley.

Willey, J., Sandman, K., and Wood, D. 2022. ISE Prescott’s Microbiology, 12th edition. McGraw Hill.

Woodin T., Carter, V. C., and Fletcher, L. 2010. Vision and change in biology undergraduate education, a call for action – initial responses. CBE Life Sciences Education 9: 71-73. doi: 10.1187/cbe.10-03-0044.