Experimental case studies to engage higher cognitive skills

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Instructors often find it difficult to write questions that are open ended in nature (4) and that engage students at higher levels of cognitive complexity, for example, Bloom’s taxonomic levels of analysis, synthesis, and evaluation (1). As a consequence, typical pedagogical settings seldom challenge students to engage in learning on those levels. As these higher levels of cognition are generally expected of graduate students, we sought to engage and evaluate graduate students by supplying raw, generally unpublished experimental data from a faculty member as “experimental case studies” requiring their analysis, their creation of tools, and their evaluation against each other and existing literature.

METHODS

Our method was implemented in an 800-level graduate course on Cell Mechanics, Adhesion, and Locomotion in the Department of Biomedical Engineering at the University of Virginia. The objective of this course was to deliver a quantitative description of the molecular basis of cell adhesion and motility, with an emphasis on the underlying physical chemistry and its implications for cell physiology. Class enrollment was 14 second- and third-year graduate students who self-selected into the class according to their research interests. The course was lecture based rather than a colloquium; current research was included in lectures, but readings from the primary literature were only required as part of the experimental case studies themselves. Mechanics of Motor Proteins and the Cytoskeleton was used as a text (2).

The course was divided into four major topical sections: polymer mechanics, molecular motors, adhesion and intermolecular bonds, and cell motility and chemotaxis. Homework to directly reinforce lecture material was occasionally assigned. In addition, each section of the course was concluded by an experimental case study rather than an exam. Students were provided with raw experimental data from the course director’s laboratory that was relevant to that section of the course and asked to derive key parameters from those data. The case studies for each section of this particular course can be summarized as follows:

Experimental case study 1: polymer mechanics (cytoskeletal filament mechanics). Use movies of fluorescent actin filaments diffusing in two dimensions to determine the flexural rigidity of actin filaments and estimate their Young’s modulus.

Experimental case study 2: molecular motors (finding motor steps in noisy traces). Estimate the velocity, step size, and mean step duration of an in vivo molecular motor from noisy laser trap data (3).

Experimental case study 3: adhesion and intermolecular bonds (the nature of catch bonds). Characterize data from single P-selectin/P-selectin glycoprotein ligand-1 forced bond rupture experiments.

Experimental case study 4: cell motility and chemotaxis (modeling molecular-scale active and passive cell mechanics). Develop a theory to explain data from microvillus extension experiments.

Note that the objectives of each experimental case study became progressively more open ended (less well defined and broader in their possible approaches) as the course progressed. Students were supplied with raw data in the form of tabulated values or digital images along with a whitewpaper detailing the experimental methods that were used in the collection of the data and information about the form of data that they were provided (e.g., image formats and calibration factors). See the online Supplemental Material for an example of experimental case study 2.1 Each whitewpaper was 1–3 pages in length and had the following structure:

1. Assignment/goals
2. Background information
3. Experimental design
4. Experimental conditions (e.g., temperature and concentrations)
5. Rules (e.g., team sizes and confidentiality of data)
6. Reporting (written and oral requirements)

The following statement was included in the whitewpaper: “Feel free to derive your methods from the literature, but report your sources in full. If you come up with a new idea or approach that significantly benefits our data analysis, you may be included on the manuscript reporting these novel data.” This incentive was to promote the synthesis of information rather than relying strictly upon published approaches to the analysis.

Students were given 1 wk to complete their analysis, working in self-selected teams of three students/group. Each team was required to submit a 2-page written summary of their analytical approach and their conclusions. They also presented and defended their approach to their peers in a 5- to 10-min “chalk talk.” Each of the four case studies accounted for 10% of the student’s final grade. The balance of the class grade came from homework assignments (40% in total) and class participation (20%).

RESULTS AND DISCUSSION

For groups whose work in toto would best be categorized as “analysis,” the majority reported parameters that were within reasonable statistical errors of one another and with the existing literature. In-class discussion after the oral reports usually identified the sources of major discrepancies. The most common points of failure included 1) not considering whether their values were reasonable with respect to the literature and 2) not leaving sufficient time to repeat the analysis. In experimental case studies 2 and 3, at least one team devised their own approach to the analysis rather than relying on the published literature. For example, in response to experimental case study 2, a team addressed the problem by transforming the noisy data into the spatial frequency domain, filtering, and performing autocorrelation in that domain. While this approach was judged to be a specific case of a more general published technique, the fact that it was so would not have been obvious to a nonexpert. The solution also reflected both a solid understanding of the underlying problem and an ability to draw upon the techniques...
of another discipline in a nonobvious way to achieve a solution. This was interpreted as reflecting a high degree of cognitive synthesis.

The overall course rating from online university course evaluations was 4.18 on a 5-point scale, which was significantly higher than for other 800 level courses that same year \( (P = 0.002) \) and higher than a previous offering of the same course taught using quarterly exams rather than quarterly case studies \( (P = 0.048) \). Student feedback, both in person and in the online course evaluations, was positive. “The case studies were very valuable in learning how to deal with experimental data,” to quote one student. Another expressed his admiration of the willingness of a professor to share their raw data in a relatively open forum for analysis, comment, and discussion. However, as all these data reflect students’ self-reported preferences, they should not be interpreted as evidence of educational efficacy.

Nonetheless, this approach encompasses several levels of cognitive complexity and promotes the synthesis of didactic learning with laboratory practice in a nonlaboratory setting. “Application” was promoted by requiring students to apply theoretical concepts to practical situations in experimental science. “Analysis,” too, was promoted by requiring students to classify data, deduce a logical approach to solving the problem, and identify relevant resources for solving the problem. Finally, “synthesis” was promoted by encouraging students to formulate their own analytical approach to solving the problem rather than relying solely on published approaches.

Perhaps just as importantly, the approach helped the instructor write open-ended questions when ordinarily it is difficult to do so in a way that is accessible to the student and where the objective of the question is clear. By presenting the question in an experimental context with well-defined conditions, it became relatively easy to pose questions and construct problems to which there is not necessarily a known answer or a single correct solution. There was also an intrinsic benefit to both the student and instructor in having the data examined in new ways by a diverse group in a relatively low-stakes setting.

This approach should be easily generalized to any high-level graduate physiology course focused on the instructor’s area of research expertise and where raw and novel quantitative data are routinely generated. It is vital, though, that such an approach be used at an educational level where students would have had sufficient supporting coursework (e.g., physics, chemistry, and applied mathematics) to complete the assignment.

**GRANTS**

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**REFERENCES**