WHEN IN SCIENCE, DO AS THE SCIENTISTS DO: WRITING AND EVALUATING RESEARCH PROPOSALS IN AN UNDERGRADUATE GENETICS COURSE

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I describe an educational exercise in which the students in an undergraduate genetics class wrote short research proposals and then evaluated them in a process analogous to scientific peer review. The results of two independent runs of the exercise are described, including analyses of quality.

In 1990, after a sabbatical leave at a federal research institute, I returned to the University of Minnesota wondering how I might contribute more effectively to the education of my students. I wanted an activity that would engage them in the scientific process, that would emphasize logical development and critical thinking, and that would require written and oral communication. I also wanted something that would explore the ramifications of my lectures and lead the students beyond the textbook, acquainting them with original scientific literature. Total immersion in research during the previous year had suggested a strategy for achieving these goals. Why not have the students do exactly as scientists do? Let them find an idea and write a proposal to research it. Then they could turn a critical eye on each other and evaluate their work through peer review in the classroom.

I implemented this plan in my genetics course in 1990 and again in 1991. Each time there were about 100 students, mostly juniors and seniors majoring in biology, but also some beginning graduate students. I asked each student to write a short proposal designed to win a fellowship to conduct genetics research in an established laboratory. The sponsoring laboratory had to be specified on a cover sheet. Each proposal was limited to a few typed pages and consisted of three separate sections: Goals and Specific Objectives, Scientific Background and Rationale, Methodology and Research Plan. A bibliography was also required but it was limited to one page. A title and a 75 word summary were to be included on the cover sheet.

This assignment was announced on the first day of the ten week term and the finished proposals were collected at the end of the eighth week. Handouts distributed in the fourth week specified the proposal format and provided tips on how to find a topic and formulate goals. In 1991, a selection of proposals from 1990 was reserved in the library for students to peruse. I also held brief classroom discussions about proposal-writing strategies.

Each student submitted 11 copies of the proposal. I sorted these into packets and organized the class into peer review panels consisting of 10-12 members. Each member reviewed a packet of 10 proposals and wrote formal one-page critiques of two. At the end of the term the panels met for two hours to discuss and evaluate the proposals in their packets. As in professional grant reviewing, the panel members gave each proposal a score. We used a 10 point scale, with 9-10 being outstanding.
8-9 excellent, 7-8 superior, 6-7 very good, 5-6 good, 4-5 fair, 3-4 marginal and below 3 unsatisfactory. Either I or a teaching assistant also read the proposals and attended the panel meetings, but only as observers. We did, however, quietly assign scores to the proposals after hearing the group discussion. A student was designated to chair each panel. The discussion of a proposal was led by the students who were assigned to criticize it, but anyone could make comments. Students were rated for participation by me or the attending teaching assistant; we also read all critiques and rated them. Ratings of proposals were based equally on the average of the scores given by the panel members and on the score given by me or the teaching assistant. Ratings of participation, critiques and proposals were weighted 10%, 20% and 70%, respectively, to determine the final grade of each student. Scores, annotated proposals and critiques from peers were returned to the students at the time of the final exam.

What kind of proposals did the students write? Many concerned aspects of eukaryotic gene organization and expression, but there were also some about prokaryotic genetics, usually with a practical angle. In this era of genome mapping, it was not surprising to find that many students proposed to locate genes responsible for human diseases. Gene therapy was also a popular subject. Other topics included viruses, molecular evolution, chromosome structure, transposable elements, behavior genetics, protein structure, applications to agriculture, DNA replication, mutation and DNA repair. Many of these subjects had been treated only lightly, if at all, in the lectures in the course.

What about quality? In 1990, the instructor's mean score for the proposals was 6.81; in 1991, it was 7.03. These compare to means on the midterm and final examinations of 6.26 and 6.67 in 1990 and 5.80 and 7.06 in 1991. The scores for the proposals were about as varied as the scores for the examinations, suggesting roughly the same distribution in quality. Correlation analyses support this view. The correlation coefficients for the scores on examinations and proposals were 0.22 and 0.32 in 1990 and 0.57 and 0.57 in 1991. For comparison, the correlations for the scores on the two examinations were 0.61 in 1990 and 0.71 in 1991.

A few proposals were beautifully developed, with clear goals, a cogent rationale, informative background and appropriate methods. Others were simply awful. However, most of the proposals were done reasonably well. As expected, graduate students outperformed undergraduates. The greatest weakness in the proposals was with methodology. Most beginning genetics students lack the technical know-how to propose feasible and effective methods. However, they do have interesting, even grand, ideas, perhaps because their minds have not yet been encrusted with technical details. In general, the proposals were put together well, with each section fulfilling its purpose, but there were grammatical and stylistic shortcomings.

How successful was peer evaluation? The panel discussions varied from mediocre to excellent. Some were positively thrilling. Each student was required to speak on a minimum of two proposals. Most spoke about many more. Sometimes the comments were trivial, pointing out typographical errors and grammatical flaws, but often they dealt with structure, logic, accuracy, significance, scientific merit and depth of understanding. The students showed remarkable sensitivity in making their criticism, realizing I suspect, that fairness and a constructive approach are essential for the success of peer review. Objectivity in the review process was fostered by keeping both the authors and reviewers anonymous. In addition, no author was a member of a panel that reviewed his or her proposal.

For me, this whole activity was an experiment. I wanted to find out how students judge written material. One way of investigating this question is to compare the scores given by the students with the one's given by me or the teaching assistants. The correlation coefficients were all strongly positive: 0.66, 0.81, 0.77, 0.71, and 0.78. This sug-
gests that students are reasonably good judges of quality and that peer evaluation can be used to ease the instructor's burden of grading papers. As an aside, I should mention that after the panel discussions, many students spontaneously remarked how difficult it was to evaluate the proposals. Several also expressed sympathy for those of us who grade papers as stock in trade. More significantly, many remarked that after reviewing the proposals, they were in a position to write a much better one themselves. This suggests that much was learned in the peer review process. The students readily identified good elements to be emulated as well as bad ones to be avoided.

The students viewed this as a difficult assignment. Some were completely overwhelmed. Others found it stimulating, even exhilarating. They frequently described it as a challenge. Some were very uncomfortable moving beyond the certainty of the textbook. They struggled with the process of creating their own project. They complained of the stress but appreciated the freedom to think for themselves. A few oddballs even thought it was fun. The peer review panels were deemed very worthwhile, but a few students expressed reservations about being graded in this way. On balance, I think the activity was a big success, but I also think that it is better suited to more advanced courses with fewer students. Already instructors in some of the graduate courses in genetics, cell biology and molecular biology at the University of Minnesota have tried it out with considerable success.

Did the activity have any intellectual significance? Obviously, every student learned about a particular topic—for example, the human fragile X chromosome, genes for nitrogen fixation in bacteria, RFLP analysis in maize—but they also learned about the process of scientific inquiry. This is Research with a capital R. Many people seem to think that research is groping around in the dark, a haphazard search for the strange and peculiar, governed mainly by luck. But most research I know has been done in rather strong light. It is systematic rather than random, and depends more on dogged perseverance than on simple good luck. The students who wrote proposals in my genetics course learned that research requires a point of view. It begins with an idea that must be developed logically and carefully. Every effort must be made to articulate the point of view persuasively. Otherwise, funds to support the research will not be forthcoming. This is the world we, as scientists, live in, and I think our students need to be told about it.

What about the activity's educational significance? Few of my genetics students are likely to enter careers in which they will write or review research proposals. However, many will enter professions that will require persuasive, expository or critical writing. Some will have to compose impact statements, write job or product evaluations, or formulate clinical and research reports. Others will have to analyze these materials critically. In the cybernetic society of the future, everyone will need the skills to gather, assimilate, organize and evaluate information. People with the ability to articulate messages clearly, to specify objectives and formulate plans will have an advantage, with the greatest payoffs going to those who can translate their ideas into tangible outcomes. Educational activities like the one described here, with its emphasis on critical writing, speaking and thinking, are therefore not without practical significance. More importantly, however, such activities can engage a student in the creation of a realistic "product" from a carefully structured process. They can heighten the sense of individual responsibility for the activities in this process and allow for the feeling of definitive fulfillment that comes when the process is completed.