Chapter 4

Student Projects

Involving students in laboratory and observing projects is often one of the most effective ways of teaching astronomy. The first two papers deal with involving students in projects of original research. The following pair of papers discuss using existing data of research grade. Next, three papers discuss student observing with telescopes, for visual observing and using CCD's and photometers. Finally, we read two philosophical statements about the nature and value of student laboratory and observing work.

THE ROLE OF PROJECTS IN ASTRONOMY EDUCATION

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1. Varieties of Project

At first sight, there may appear to be a very wide range of project situations that are in use. Students may seem to be doing the equivalent of postgraduate work, or may seem to be working on contract basis, or may even seem to be doing rather long term laboratory exercises, or some mixture of all three. However, there are in essence two major types of project situations — the free-scope project and the set-piece project.

The free-scope project attaches importance to the selection of project topics by the student. The student may be told to select a problem from the entire spectrum of problems offered by the science of astronomy, and to get on with it, or there may be guidelines to restrict the choice. Nevertheless, the choice of topic is the prerogative of the student, and it is believed that the effort of making that choice is important in the teaching/learning process. Because of the range of formats for free-scope projects, it is a convenient form to adapt to meet varying local circumstances.

The set-piece project depends on there being a set of specific projects available, and choice is restricted to that set only. It is usual, because of investment in necessary equipment, for such projects to be available for several years as a minimum. Projects that decline in scope can be phased out and replaced by fresh examples. Such a system is time-consuming to devise and set up. It has advantages in that

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by having well-defined boundaries, the assessment and inter-comparison of students is easier than in free-scope projects. Economies can also be effected by assigning students in pairs.

The boundary between free-scope and set-piece projects is not sharp. Free choice can be limited by availability of supervisors, equipment, availability of data, or accessibility of celestial object; the set-piece project need not inhibit enthusiastic student initiative. Often a menu of possible projects is predetermined, and the student is given a choice within the menu. Other students will shop around members of staff to see if they have an interesting problem on offer. The mix can become so blurred that it may not be immediately clear to which class any project actually belongs.

The mode of operation of the projects also varies considerably. In some schemes, each project student is heavily supervised, while in others, the student sees the supervisor only if in difficulty. Some schemes involve the student with, and absorption into, a research group: in others the student works completely alone. Again, the wide range of modes of operation of project schemes allow ready adaptation to local conditions and university regulations.

Projects must also be assessed. There are many mechanisms ranging from continuous assessment by the supervisor, evaluation of a written report, or a single short talk on the work done or a combination of several such elements.

Adequate time must be allocated for project work and its assessment. It is clear that it will be rare for an undergraduate project to break new ground. Yet it is the essence of project work that it is new to each undergraduate, and should represent something of value when complete, whether it be a new item of equipment, a set of complete programs for data analysis, or the analysis of a spectrogram that might otherwise not have been analyzed. Assessment is a considerable problem in its own right, and will be returned to later in this paper. At this point it is sufficient to say that any assessment scheme must give the student credit for adequate work done, ability to draw conclusions from the work, and to see how the project fits in with Greater Astronomy. A student should also receive credit for being able to present a clear, well-set-out report.

2. The University College London Astronomy Project

Perhaps the best way to illustrate project work is to take a particular example. I shall take the Project Course that forms a part of its final year program in the B.Sc. Degrees in astronomy, astronomy/physics, and mathematics/astronomy. The Project course is compulsory in the degrees in astronomy and astronomy/physics (in the latter, the students have the option of electing to do either the Astronomy or Physics Project), and represents 25 per cent of the final-year workload. In mathematics/astronomy, the project is optional, and has a reduced demand being equivalent to a 12.5 per cent of the year's workload.

The Astronomy Project operates in the free-scope mode (the UCL Physics Project operates in the set-piece mode). The student is free to choose a topic that

the course directors consider has sufficient astronomical flavor. Choice ranges from cosmology to Earth resources, and even astronomical history or philosophy are not excluded. The student is asked to consider a project topic during the vacation before the final year and this topic is discussed with the course directors at the beginning of the final year. Students are simply advised to consider any logistical constraints, such as accessibility of objects to be observed, availability of data, and computational requirements. Many students make a tour of the research groups to see what may be on offer (thereby introducing an element of the set-piece project) and indeed the majority find a topic this way. Nevertheless, a number of students each year arrive at a choice of topics themselves, or at the very least have identified an area of interest in which to define a project topic. Since the project is compulsory for astronomy students, the course directors keep a number of possible projects on hand for the few who seem unable to reach a choice for themselves. (It is surprising that by the final year of a degree course, there are students incapable of identifying an area of interest.) The UCL astronomy project, while free-scope in essence, has set-piece elements within it.

The project course is run by two course directors who are available for discussions with the students on any matter concerning projects from science and supervisors to logistics. The course directors discuss the proposal for projects with the students at the beginning of the final year, ensuring that the proposal is possible and represents a reasonable astronomical endeavor. This discussion is fraught with pitfalls — clearly one cannot allow a student to proceed with a project that demands observations of objects that will not be available until nearly the time when the project must be concluded. It is discouraging for the student to be told that his or her proposal is not good science (one needs to be wary of dismissing a proposal by a colleague for the same reason!), but with a little exploration, amendment, reconsideration, and enterprise it is usually possible to find a reconciliation of student expectation, a scientifically worthwhile project, and a willing supervisor by the end of the first four weeks of the Autumn term. At this stage, the student submits a short statement of the project topic. The supervisor countersigns the proposal to show that the logistical implications are accepted and can be met as of the date of signing. This means that, for example, data are available then and are not awaited from some outside source. The students are interviewed about 2/3 of the way through the Autumn term to ensure that they have begun work and are not procrastinating. Problems are identified, clarified, and, we hope, sorted out. On return from the Christmas vacation, the student presents a short report on work done and plans for the upcoming Spring term. This report is again signed by the supervisor to indicate its accuracy. The report is assessed by a course director and credit can be lost for failure to meet the submission deadline. The students accompanied by their supervisors if they (the students) wish, are interviewed by the course directors in the middle of the second term. This is a crucial interview. If it is felt that the student has made insufficient progress with the project, the student is not permitted to proceed with a full project, but is told to halt that work, and must submit an extensive essay review. Students are also questioned to ascertain that

they are not devoting time to the project that should be spent on other courses. Finally, on return from the Easter vacation, the students submit a report on their project for assessment, to be followed two weeks later by a 20-minute project talk, given before a small audience of lecturers and other students. Each report is assessed by the supervisor and another academic close to the topic of the project. All reports and talks are assessed by a course director, so that the final grade awarded is a moderated amalgam of all three assessments.

In assessing the project, all three assessors should use similar criteria, though they may weight these criteria differently. One for example will give a substantial weight to the project talk — another will give it almost no weight. However, all assessors are looking for a capable piece of well-presented scientific work. It is surprising how little disagreement in mark differing philosophies achieve — a spread of 5 per cent is common, and less than a degree classification band (about 10 per cent) will account for all but exceptional cases.

It is hard to say whether or not the students like projects — in all but a few cases, most like doing their project work. The report is normally regarded as a chore and the talk is universally disliked. The project report, even though it will be available for consultation by future generations of project students, retains some vestigial remains of the confidentiality of the confessional whereas the project talk exposes the soul to the gaze of the masses. The project talk is a nerve-wracking and not-to-be-repeated ordeal for most.

In the UCL Astronomy Project, choice of project topic is seen as an essential part of the training. A final-year student should be capable of choice of topic and be able to justify that choice. It is also regarded as important that the student should be able to write a report understandable beyond immediate practitioners of the project topic, which demonstrates clearly the work the student has done and the conclusions which can be legitimately drawn. The student should also be able to communicate the essence of the work and conclusions verbally. These are skills that are featured nowhere else in the UCL Astronomy-based degrees. The scientific quality of the project should demonstrate the student's capability in following an astronomical problem, or skill in practicing an astronomical technique. Over the years, the project course has brought forward projects of great professionalism, and have been published in the refereed astronomical literature. Most are simply good reports of good work done. Some are admittedly awful — being inept, inaccurate, innumerate, and illiterate. Yet even that rump end have probably learned something useful in the process. The project may bring forward students who have not shown distinction in any other way. Conversely, the project may undermine students whose previous examination records have been impeccable. It is clear that the project is a different measure of a student from standard essay-type examinations.

3. Arguments in Favor of Projects

The argument most often advanced in favor of projects at the undergraduate level is that they offer students the opportunity to attempt to study a real problem in

the raw, and not as predigested in textbook and lecture note. This is a compelling argument for most academics, since that is the essence of research. The project, they contend, is a valuable way of assessing students as possible research workers. Standard examinations offer little scope for real assessment of research potential, other than the broad assumption that he or she who does well in examinations is likely to be a useful research worker. By and large, such an assessment is adequate. The project supplies further evidence for research potential, even though the range of that evidence is perhaps more limited than most are willing to admit.

That the project offers a chance to get to grips with a problem could be an illusion. Even in a free-scope project, the opportunity to attempt something really new is unlikely. The important part of the well-organized project is to remove the student from the lecture/textbook situation. The student has an opportunity to see real astronomical data, to really see what noise means, to appreciate how data must be handled to extract meaningful information, and above all, to appreciate what a difficult and demanding task an original investigation can be. The pace of information transfer of a three-year degree course, becomes abruptly slowed in the project through the demand on student energy is increased. Some students do not survive the spartan exposure by project.

The students who do survive (*i.e.*, the majority) learn in varying degrees about the difficulty of making sound astronomical progress. They learn that a consideration of error bars is as important as actual measured values. They learn about judgment. They begin to understand techniques in a way that no number of set experiments in laboratory classes will teach. They make a start in learning to communicate and to realize the value of the astronomical literature as a resource. They will learn about themselves. They will begin to realize what type of problem drives their enthusiasm, and what may cause them to procrastinate. They may even realize that an ambition that sustained them through three years of university study is not practical, but that its likely lack of realization is not a disaster either. Projects help people mature and gain experience. The gain in confidence between the first- and second-term interviews is often seen as a step function.

The argument in favor of projects should be not that they give students a taste of research but that they give the students freedom from the predigestion of textbook, lecture, and formal laboratory classes. They give students a chance to try for themselves at their own pace, and to learn how to handle their acquired knowledge in attempting to understand a particular problem or technique.

The project is not a wonder antidote for standard examinations, but is another measure of particular individuals. The project is only one among a number of the measures.

4. The Argument Against Projects

While projects have advantages, there is no doubt that projects have serious disadvantages and irreducible drawbacks. The first objection is that a project — for all its apparent similarity to a research situation — is essentially contrived, and, in

order to be scheduled within the constraints of an academic year, simplistic. It could be argued that undertaking project work only gives students a false impression of real scientific work so that it would be best were projects avoided. These arguments have force and sensibility.

The UCL Astronomy Project must be started, read about, worked on, concluded and reported upon, within the space of 30 weeks of which 7 are vacation. It represents 1/4 of a full year's work, *i.e.*, approximately 70-75 equivalent lecture hours (*i.e.*, 70-75 actual hours in the lecture rooms, plus time spent additionally on that lecture course). A realistic estimate would be 150-200 actual hours, or not more than 1 day's work per week (on the basis of a 30-week period). Clearly, any project that can be started and concluded in such a period must offer only a cursory introduction to scientific investigation. Any project scheme must suffer such limitations of timetable. Again, the time given to the mechanics of understanding the problem, actually executing an adequate amount of data reduction, and writing the final report must take up so much available time that there is little time to think the problem through — surely the most valuable part of the exercise. Unfortunately, there is ample evidence from many reports that this has been the case. Indeed there is considerable evidence from the project reports that many students fail to appreciate the astronomical context of the work, as well as failing to draw adequate conclusions from what they have done. The impression gained is "I was told to do this, that way, and I did it, but I don't know way I did it, or why I did in that way." Such a student has gained little scientific insight from the project. Other students will give a confident report of what they did, yet under questioning reveal little grasp of the underlying science. At best, such students may have learned a technique, but little else.

The scientific value of the work done is often questioned. Why should a student be permitted to waste time and resources to produce results that are not even publishable in the scientific literature? Is it not more valuable for the student to take extra courses, from which something useful can be learned? Since pressure on research resources is severe, is it not more sensible to reserve resources for the productive scientific workers? These are arguments which are not easy to answer, because they are true, although in a limited sense.

Of more importance is the psychological trauma inflicted by projects on the student. Many students will claim they are disadvantaged by examinations. In the case of standard examinations, where the situation is well understood by examiners and examined alike, the number of people actually disadvantaged is about an order of magnitude less than those who claim such disadvantage (on the grounds that the greatest number end up with lower 2nd-class degrees, though the argument does have an element of circularity!). In the case of projects, a significant fraction are actually disadvantaged by the project situation. This is in very large part because of reliance on standard essay-type examinations almost exclusively in the school and university system. The project is a new experience and most are not equipped to meet the challenge. The mere fact that a project cannot be resolved like a homework question is unsettling to many. To some, the sheer challenge may be completely

overwhelming. The project route is littered with those who have effectively given up somewhere along the way. Some of these may achieve a poor passing grade, others fail unequivocally, yet others do not complete a report, and some do not attend for their talk. The project does impose additional strains on the student. They feel the project format does not allow them to acquit themselves in the way they feel does them justice — a justice they are perfectly capable of achieving in the standard examination format. The project talk often produces refusers. It is frightening to stand up and present ideas to an audience (an audience often more sympathetic than the speaker imagines) and then to respond to the challenge of being questioned by acknowledged leaders in their subject. It requires a cool head to appreciate that the renowned world authority is seeking a simple and not a sophisticated explanation.

The project is often critized on the grounds of subjectivity in assessment. It is argued that no supervisor will want to fail his or her own student — it would be a reflection on the research capability of the supervisor. Again, two assessors could disagree in their respective marking of the same project. The reasons could range from peer rivalry to diametrically opposed expectations of the student. It has been alleged that some project assessments are assessments of the supervisor. It is clear that assessments of projects will have a subjective element of necessity. A project that fulfills the aims and achieves the result sought is necessarily pleasing to a supervisor. A project that does not achieve the expected result, or falls short of expectation, may not please, but gratification of supervisors is not the object of undergraduate work. The value of a project to science may not be seen in the same light by two different assessors. Assessment problems will not arise with assessors of integrity, but any scheme must have very clear aims what a project examination is trying to measure about the student and the criteria on which that judgment should be made. Each assessor may weight the criteria differently, but the criteria themselves should be visible and agreed.

5. A Justification of Undergraduate Project Work

I am a believer in the opinion that undergraduate project work is a valuable teaching/learning experience and a useful measure of potential that is clearly differentiated from standard essay-question examinations. I recognize all the objections against projects and I feel particular concern for the stress that project work places on students. Each year produces a fresh crop of project difficulties related to student stress (some of the stress is self-induced through poor judgment on the part of the student) but learning to cope with stress in its many manifestations is part of learning to cope with life. Therefore, an element of stress is necessary in the project situation. However, assessment strategies must be flexible and sympathetic to cope with the effects of excessive stress. The form of the project must be well defined, so that students, supervisors and assessors are clearly informed on what is expected and the schedule that is being followed. But in order to cope with excessive stress (affecting 10-15 per cent of the students) the rules may need flexible interpretation, which is both fair to the stressed student and the remaining unstressed (!!) students.

To maximize the benefit of the project a fair assessment scheme needs to be devised. A very clear but very fine distinction has to be made. The project assessment *must not judge* the quality of the science implied by the project — it is to judge the quality of the science displayed by the student within the context of the project. This is the crucial distinction that has to be kept clearly in mind at all stages of the assessment. It is a distinction that is crucial to the success of the free-scope project. Set-piece projects can be set up in such a way that they all contain about the same amount to work even if some set-piece projects have more student appeal than others. The distinction just made has reduced force in the set-piece project area. In the free-scope project, the course directors must ensure that each and every accepted project has sufficient substance. Beyond this, however, the assessors must look for:

a) student awareness of the scientific context of the project;

b) the understanding the student shows of the problem to be tackled;

c) the contribution of the student to a solution of the problem;

d) the logistical approach of the student

e) the ability of the student to draw conclusions from the work done;

f) the ability of the student to report scientific context, the problem to be tackled, the methods used, and to present data and draw conclusions both in writing and orally (including the quality of the final report);

g) the breadth of the student's reading around the project topic.

Other factors may enter into particular assessments. The weight given to factors (a) to (g) will vary with assessor. There is no realistic way to enforce uniformity, and indeed it would be counter to the spirit of student projects to seek such uniformity. However, all assessors should agree on the fundamental basis of the assessment scheme. In the assessment, supervisors will place emphasis on (c), (d), and (e). A moderator might put more emphasis on (a), (f), and (g). Clearly moderator and supervisor will be looking at the student from well-separated points of view. A second assessor, neither supervisor nor moderator, may wish to emphasize (b), (e), and (f). It is interesting to reflect that assessors will sometimes agree to within 1 per cent, often to within a degree class, but occasionally vary by several degree classes in their assessments. The experience of normal agreement to within a degree class is encouraging and removes much of the criticism of project assessment as subjective. To achieve this objectivity, a minimum of 3 assessors for each project is essential — the supervisor, an assessor close to the science, and a moderator. The moderator must assess all the projects presented in a given year, and have sufficient authority to decide the relative standing of a project among its peers. How the moderator achieves this goal is quite open. I have found discussion with the other two assessors normally resolves any difficulty. In the last analysis, the moderator must have final responsibility for the assessments.

The assessment scheme must also be made clear to the students. The students

must know the time schedule for the projects and be aware of the important deadlines at the start of the project period. They must be told of the mechanics of the assessment and the basis on which it is made. The students should also know who their assessors will be (from the beginning the supervisor and moderator are clearly identified — only the second assessor in the UCL Astronomy scheme is not selected until the project reports are in the writing-up phase). Students can then see that the system is fair to them and be aware of what they have to achieve and when. A fair scheme that is well known to all involved goes a long way to resolve most of the criticisms that assessment is subjective, that one assessor marks another's science, and that students receive only rough justice. Nevertheless, the scheme only works optimally if all assessors approach their task with integrity.

The criticism that projects are a waste of scarce resources is much harder to counter. Projects do consume resources. One can always restrict the maximum expenditure for projects in actual cost terms; *e.g.*, at UCL no project can exceed an expenditure of £200 on materials. However, there is no quantifiable estimate of what each project costs in terms of computer resources, technician time, other support staff time, and supervisor's time. There is no doubt that such costs would be substantial. The criticism of diversion of resources has foundation — projects are costly. The argument must be based on balance. Degree-level students represent a substantial investment in educational resources. In U.K. terms, a current estimate would be that £20,000 has already been invested in each undergraduate by the time they enter the final year if only recurrent expenditure is considered. Therefore their final year should offer the best opportunities to maximize the return on outlay. It could be argued that the best also includes a range of experience. There is no doubt that project work represents a very different learning process from attending lectures. Students are placed in a situation where they must use their accumulated knowledge and experience to tackle a problem whose solution may not be obvious. Most science graduates are going to meet exactly such situations for the bulk of their working lives and a brief introduction is therefore of value. If you can afford it, the project is a useful luxury.

But even if one is willing to devote resources to the project, should strain on students be considered a major disadvantage? There is no doubt that project work enforces strain on students. While most students enjoy the actual project work and research group contact that goes with it, there remains the deadline of the report submission date and the implication that something must be achieved in a finite time. Those requirements can cause stress, sometimes severe stress. There are students who do not enjoy the freedom of the project work — they are discouraged by the amount of information to be acquired, new techniques to be learned and the sheer exasperation of failure to get the problem to yield. They often become depressed by how little they appear to have achieved and can magnify out of all proportion the alleged progress of their peers. Such depression can have disastrous effects not just for the project course but also for other more conventional course work as well. The project leaves its mark and is not neutral — it can both make and break. This is why at UCL we have the safety net of a half-unit essay review

type of project. There must be a safety net to catch those who are not coping in the full-blown project situation. Those who do not cope must not be regarded as failures, otherwise injury to self esteem may injure their chances in standard course work. The project situation should be tough and be accepted as such, if it is to have educational value, but should always be engineered with loopholes so that those who do not cope can attain a recognized and respected fall-back position. The value of the fall-back position should be made clear to all students at the outset. With such safeguards, the strain on students can be kept within acceptable limits.

It has been found in practice that the most stressful part of the UCL Astronomy Scheme is the project talk — given before an audience of assessors and students. For most students this is their first experience of speaking in public. They must put their ideas on the line and defend what they have done. All students are nervous, some excessively so. Only a few manage a good performance striking the right balance between context, conclusions, and methods with appropriate illustrations. Most stagger through, and their inexperience in knowing how best to illustrate their work shows up painfully. But they are not being assessed for their elegance of presentation and the experience is an invaluable learning experience even if a hard one. But worse is to follow — questions. About half the students cope with questions. The other half stagger blindly from straw to straw and some are reduced to silence by what they perceive as sophisticated questions from the internationally famous in their subject. But the more internationally famous the questioner is, in my experience, the simpler the answer that is required. Although told of this, it does not conform with undergraduate perception and mythology! However, all students after the talk would agree it was not as bad as anticipated. It is the anticipation that drives some to hide in their lodgings or the Union Bar, or anywhere they think they will not be found. In extreme cases, some students are allowed to give the talk only before their assessors. I would have doubt about the value of the project talk — were it not for the fact that talking about one's work is such an integral part of scientific life.

Conclusions

The project serves a purpose in science education — it allows the students freedom from the textbook or lecture room situation and gives them time to investigate for themselves. They learn about actual data as they come from real instruments raw and uncorrected. They learn about signal/noise in a direct way and the weight that should be assigned to conclusions. A few students take to projects like a duck to water, most learn to live with them, a few are disadvantaged by them. Projects are expensive in the time of academic staff who act as supervisors and their research groups. Projects are also time consuming to assess adequately and fairly. Without the investment of adequate manpower resources, projects are likely to be a disaster. With proper investment, projects can be a valuable learning strategy in which students learn perhaps more about themselves and their abilities than in any other learning situation. While recognizing the difficulties and dangers, it would be my view that projects win by a small but significant margin.

Discussion

L.C. Hill: *Have you found students who performed at a significantly different level (either better or worse) in their project as opposed to their performances in other academic work?*

D. McNally: By and large, good academic students do well on their projects. However, some 2rd and 3th class students have turned in professional, polished projects. You also find that some 1st class students (on examinations) find projects frustrating because progress is slower than they are accustomed to.

Comment

Jay M. Pasachoff: We have a similar program of research projects at Williams College, and we view it as a major enticement for students to come to Williams and to major in astronomy. Still, the students often come up against the same problems so perceptively listed by Professor McNally. I think that giving Professor McNally's article to new undergraduate thesis students, as I shall surely do, will help them greatly.

MAXIMIZING THE EDUCATIONAL VALUE OF STUDENT RESEARCH PARTICIPATION

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1. Introduction

The Maria Mitchell Observatory monitors variable stars photographically and has lately begun to receive photometric data remotely. The staff consists solely of the director and undergraduate student assistants during summer and January vacations. Research topics are chosen for both their scientific interest and their educational potential.

The scientific goal is to improve variable-star statistics by answering any unresolved observational questions. Lately the emphasis is on pulsators in the Cepheid instability strip. Can we watch the stars grow older? We look for deviations from a single, constant period.

The educational goal is to give the student assistants a realistic sense of the research process, beyond what is usual in early undergraduate years. The selection criterion is a university record such that a career in astronomy is a realistic pos-

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