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John and Graeme, Undergraduate Apprentice Researchers

Two years ago while I was a postgraduate student in physics at Sydney University, I offered a voluntary discussion course to first year physics students. The course was based on reading and discussing a series of scientific research papers. I got to know two of the students in this course, John and Graeme, particularly well. When I first knew them, John and Graeme were becoming more and more dissatisfied with their courses. They were especially dissatisfied with the first year physics course, since they were most interested in that subject. We had a number of discussions about the deficiencies of their courses, the reasons for the deficiencies, and how the courses might be improved. These discussions set me thinking about and investigating this question: what would be the best course of action for a dissatisfied physics student such as John or Graeme? I was eventually led to consideration of three principal alternatives:

1. stay in the course, either passively or while trying to change it;
2. go to another institution, either a suitably progressive one or a suitably easy one; and
3. stop taking formal courses, and learn in one's own manner.

But before describing these alternatives in more detail as they apply to John and Graeme, let me tell a bit more about the two of them.

John is extremely bright. He skipped his last year of high school more or less at the spur of the moment, because the school was too authoritarian for him. John prefers to design his own pattern of study. He does not always do outstandingly well in courses because often he does not care about the subject material. Instead, he prefers to study topics of his own choosing, often rapidly progressing to advanced material, sometimes dwelling on simple points until he understands them to his satisfaction. In or out of courses, he will work immeasurably hard when he gets interested in something, going very deeply into a subject. His teachers have been very impressed when, given a chance to do an assignment project of interest or to think of, design and carry out an experiment, he shows them his capacity. On occasion he has antagonised staff members by his frank criticism of educational methods.

Graeme is also extremely bright, exhibiting many of the same traits as John in relation to learning. As well he is a fantastic organiser. Virtually single-handedly he resurrected the once moribund student physics society, arranging talks to be given each week. During orientation week after his first year, he arranged a full programme of talks and displays, giving about five talks himself (for example, one on Mars with lots of slides). He spent much time and effort attempting to arrange a student group tour of astronomical and other facilities in the U.S. He has attended various scientific conferences, such as an International Astronomical Union conference, and has not been hesitant in contacting the leading men in the field. For almost ten years he had planned to do theoretical astrophysics, and already knew his topic: pulsars (for which he had a model) and then quasars. Graeme seems to have almost boundless energy and enthusiasm, working on so many activities that some are bound to be successful.

John and Graeme are eager to learn about the particular subject areas about which they are enthusiastic: for example, theoretical astrophysics. On their own they will read advanced textbooks or research papers, work out their own hypotheses, and follow up their ideas with further study. If understanding certain advanced material requires background study of other subjects or areas, they are keen to learn the background material. For example, they may study quantum mechanics because it is necessary to understand quantum mechanics to do theoretical astrophysics. John and Graeme are unusual in that they know pretty much what things they need and want to study, and have an unabated natural incentive to use their ability to do the work required.

This latter fact is what makes John's and Graeme's courses irrelevant, or indeed worse than irrelevant for them. Only the tiniest fraction of the course material is pertinent to their immediate or long term interests. For example, at a particular time they may wish to learn quantum mechanics, but in courses be forced to cover areas, such as circuits and electronics or laboratory work, which is certainly irrelevant to them in the short term, and most probably irrelevant in the long term. But worse than this, being forced to cover certain material and to take examinations sidetracks their interest and deadens their enthusiasm. After being required to study the course material, they do not feel so keen to follow their own interests in their own time. Thus the course material is doubly a waste of time, in that it is irrelevant in itself, and at the same time mitigates against spontaneous study and learning. And while John and Graeme can easily retain the integrated insights gained in their own studies, they

are only too aware that they immediately forget what they were forced to learn.

In my opinion, what would be approaching an ideal situation for John or Graeme would be to study on their own and work on a research project, perhaps working part of the time as an apprentice to a competent researcher. They are not averse to guidance if it is for them and not that parcelled out to everyone else through course requirements. This near ideal situation would be similar to that of a postgraduate student, except that as well as doing research, John and Graeme probably would want to do rather more general study on topics not directly related to the research project than would a typical postgraduate student. Working as an apprentice researcher in a free, low pressure atmosphere would allow John and Graeme to follow their intellectual and scientific interests, to have ready access to competent help when needed, and to make an enlightened decision as to whether they wanted to pursue research in physics. However, it may be asked, could a person such as John or Graeme learn effectively or do any useful work as a researcher, before having done all the normally prerequisite course work? To indicate an answer to this question, it may be worthwhile to describe an actual experience.

During the past five years Dr. Gary Huber of Boston City Hospital has run a programme in which school students and other non-credentialed young people do medical research. Most of the students do not participate for more than four months at a given time. Initially they learn the technical skills needed to perform the research expected of them. They develop their own research programmes, and report each week on their programme and work done to a general meeting of laboratory staff, and undergo intensive peer and supervisory criticism and review. The students must complete their research, write up the results, summarise their library literature reviews, and put their results in the perspective of other work in the field. Only a very few do not complete the tasks originally outlined. As a result there have been over 40 students whose names have appeared over 150 times on abstracts and manuscripts contributed to the published medical literature.

Yet most of these students have had no background training in mathematics, physics, or biology. Many are young teenagers.

"The programme lacks entrance exams and admission criteria. Huber, as a one-man screening board, looks for motivation, not academic credentials, in the dozen or more teenagers who volunteer for work in his laboratory each year. "We underestimate what young minds can do," he says. His own motivation is a belief that the fif-

teen-year grind of conventional medical education can do terrible things to a student's head. "It's a crazy way to train people. You usually put them into a lock step of learning by rote during what ought to be their most creative period." . . .

The most revolutionary of Huber's notions is that high-school students can do useful, original research, even though their overall knowledge of medicine may be limited. He feels that Nicholas [an 18-year old black student in the programme, first pre-university student ever to present an original paper to the American Federation for Clinical Research] probably knows more about the effects of radiation on lung tissue than 97 per cent of the doctors in the world. "Getting to be really knowledgeable about a specific aspect of research may involve reading and digesting 50 or so papers. That's a finite number. It can be done. Research isn't all that special," Huber insists. "You don't need the education. You just need to know how to think." ' 1

My own experience of working with two apprentice researchers during a summer (one having just finished high school and the other, first year university) is in agreement with the results of Huber's programme. This evidence shows that working as an apprentice researcher could, for highly motivated and capable students such as John and Graeme, be a natural and acceptable context for the furthering and development of their own educational goals.

Before, I mentioned three basic alternatives for John and Graeme: stay in their courses; go to another institution; and study on their own. In my description of John and Graeme I indicated some reasons why the first alternative had become increasingly distasteful to them: instead of helping them in the direction of their natural talents and interests, courses forced upon them a programmed mass of irrelevant material under tense competitive conditions which inhibited their spontaneous urge to study and learn. But, if one finds one's courses have undesirable features, surely one can try to change them? Would not the School of Physics make every attempt to accommodate some of its most promising students, if only their discontent were known? It would seem rash to leave a university before making at least a beginning attempt to change things.

To a certain extent John and Graeme attempted to do just this. In their first year, a small group of students who were dissatisfied with the laboratory course got together and planned an alternative course. To replace the laboratory exercises they designed an integrated programme including independent experimental projects, reading of research papers, study of computing, statistics, and philosophy of science, and visits to research laboratories. Integral to the student

programme was a great deal of flexibility and choice. The School of Physics generously permitted the students to do this programme in place of the conventional laboratory exercises during third term. The student course was a great success, if one uses the criteria of enthusiasm and work done. Most of the students voluntarily spent several times as much effort and time on the programme as they earlier had been devoting to the conventional laboratory work. ²

Graeme had also attempted to change things by organising the activities of the student physics society, which hopefully would have developed the interest of students and staff in a wide range of topics and fostered interactions beyond the formal ones in the classroom. With a bit of support from the staff, these activities could have led to special interest study, research projects, new content for conventional courses, or any of a number of attractive possibilities.

Unfortunately, there do not appear to have been any lasting changes in the pattern of life for students as a result of these activities. The success of the student-organised experimental course was studiously ignored by almost all staff; no encouragement was given to further such activities. The approval for and success of the student course was greatly aided by the help and tolerance of the head of first year physics. Even so, the students felt that many staff promises in regard to that course were not fulfilled. In second year it was obvious that even the earlier sort of help and tolerance would not be forthcoming. In any case, even students such as John and Graeme have only so much energy. After all, the first year physics laboratory was only one component of one of their four required subjects. To organise, propose, and execute alternatives to all the formal work would be an enormous (though stimulating) task if one were encouraged at every stage. In the absence of such encouragement of even the likelihood of partial success, the obstacles appeared demoralisingly overwhelming.

Graeme's activities with the student physics society met with a similar apathy. Staff members were continually conspicuous by their absence from the society's functions, except when induced to give a presentation themselves. The attitude seemed to be that such peripheral activities were permissible as long as they did not interfere with the serious business of formal course work.

Thus for John and Graeme, remaining within the conventional course structure seemed at best a distasteful alternative. Attempts to change things seemed unlikely to yield lasting changes, not to mention short term changes which would affect them directly.

It was with this background that I began considering the second alternative for a dissatisfied student: go to another institution. I thought, surely there must be some place where John and Graeme could go, a place where they would be free to study what they wanted, to talk with peers and more experienced workers in a relaxed, non-competitive situation, to learn directly as an apprentice, in summary to define the essential pattern of their own learning. Or at least some place considerably nearer to this ideal than their present circumstances. Significantly, however, I was not aware of any such place myself. Nevertheless, I began asking my acquaintances if they knew of a place that would suit John and Graeme. The answer was not slow in coming. No one knew of any such place.

I also wrote to three academics I know who work in the U.S. The U.S. has an extensive range of educational institutions, and many of these have policies unusual by Australian standards. So although neither I nor my acquaintances knew of an appropriate institution, I thought that perhaps one of these people to whom I wrote might have a good suggestion. I told these people about John and Graeme much along the lines of what I have described so far here (though more briefly). The replies I received are interesting in themselves, as they exemplify the conventional attitude towards the alternatives faced by John and Graeme.

The first reply consisted mainly of a description of the virtues of the writer's university department, telling me to encourage the students to apply for postgraduate study there. The description was no doubt correct enough from a conventional point of view, including the fact that his department was flexible as far as students doing courses and research at the same time, and doing only a minimal number of required courses was concerned. (This is pretty true of many U.S. universities.) That he had not come to grips with the real problem faced by John and Graeme was shown by his statement that the department of course had comprehensive and preliminary exams for all postgraduate students, for after all they must have some way of evaluating the students.

The author of the second reply admitted he had no suggestions concerning the two students. He mentioned that Einstein had taken a job at the Patent Office and worked on what interested him in his frequent spare moments, but that of course Einstein was Einstein. At this point it may be appropriate to quote Einstein's well-known comments about his undergraduate training:

'One had to cram all this stuff into one's mind for the examinations, whether one liked it or not. This coercion had such a deterring effect

(upon me) that, after I had passed the final examination, I found the consideration of any scientific problems distasteful to me for an entire year. In justice I must add, moreover, that in Switzerland we had to suffer far less under such coercion, which smothers every truly scientific impulse, than is the case in many another locality. There were altogether only two examinations; aside from these, one could just about do as one pleased. This was especially the case if one had a friend, as did I, who attended the lectures regularly and who worked over their content conscientiously. This gave one freedom in the choice of pursuits until a few months before the examination, a freedom which I enjoyed to a great extent and have gladly taken into the bargain the bad conscience connected with it as by far the lesser evil. It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in need of freedom; without this it goes to rack and ruin without fail. It is a very grave mistake to think that the enjoyment of seeing and searching can be promoted by means of coercion and a sense of duty. To the contrary, I believe that it would be possible to rob even a healthy beast of prey of its voraciousness, if it were possible, with the aid of a whip, to force the beast to devour continuously even when not hungry, especially if the food, handed out under such coercion, were to be selected accordingly. . . .'³

Of course Einstein's example does not help all that much if one is a dissatisfied undergraduate. Einstein did get his degree; and nowadays it is hard to get a job with frequent spare moments to work on what is interesting (such as at the Patent Office) unless one has a degree first. Furthermore, if one has a degree one can usually do postgraduate work somewhere, and this is freer than most jobs anyway. I was concerned with dissatisfied undergraduate students, not ones with degrees.

Now to return after this interlude about Einstein to the second replier. He continued by saying that he didn't think universities (and certainly not his) had the money to hire assistants, but instead they would spend it on students mastering courses and research, or on technicians of proven competence, or on their own students wanting part-time work. He said John or Graeme would never be chosen over qualified students also having university degrees; and that this was unfortunately a fact of life. He noted that most young men realised this, and therefore realised that if they really wanted a career, they would have to follow the paths that society opens — paths that might be somewhat authoritarian.

The third respondent had asked around to make sure that his reply was correct. After doing this, he was sure of his reply — there was nothing in the U.S. for students like John and Graeme because of the extensive general education requirements: they would be subjected to two years worth of cultural course requirements. It seemed to him that the best thing for them to do would be to grin and bear it until they finished their under-graduate training. He said he hated to say this, but that it seemed correct.

So much for the help from the U.S. After receiving these replies, I felt sure that in all likelihood there was no place in the accessible world that would be a significant improvement over Sydney University, in terms of freedom from courses, if one wanted to pursue a career in physics. At that stage I had another idea about going to another institution. So let me save comment on the three replies until later.

Suppose one went to a university where the courses were relatively easy. Then a reasonably intelligent student would not need to spend much time to do well in the courses, and if self-motivated would have plenty of time to spend studying what was personally stimulating. This would contrast with Sydney University, for example, where (so I thought) even the best students, if doing difficult courses, had to spend so much time studying required work that they had little energy or inclination left to study what they enjoyed. The idea then would be to go to such a university with easier courses, and spend one's time doing personal study and (in time) original creative research. Then since one would be judged later on the basis of quality and quantity of research work, one could get back into the high prestige institutional circuit if desired.

In this case there are a number of institutions that satisfy the criteria — places where the quantity of work required is not so large, but also where there is staff of the highest quality. Institutions like this are not uncommon, especially in the U.S.

Unfortunately, on further thought and investigation, several flaws in my idea became apparent. First, John and Graeme were not spending an exceptional amount of time on their courses. The trouble was that the material was so depressing to them that they could not really get down to studying it very readily. But they also felt inhibited about studying what interested them because the examinable material had not been studied sufficiently. So, easy courses might not solve anything. It was the psychological pressure of having to study certain things, and not being encouraged by anyone, staff or students, to study what they desired, that was at the root of the problem.

There is another trouble with those high quality U.S. institutions with easy courses: the general education requirements. I remembered my own experience. One year, taking a heavy load of physics and maths courses, I spent more time studying a required foreign language course than on all my other courses combined (and ended up having a mental block against the language as well). I wouldn't wish that experience on anyone.

The second major difficulty with this idea is that in practice, as opposed to theory, one does not progress in the world on the basis of demonstrated ability. Let us say John or Graeme went to a high quality but easy-to-get-into and hence low status university to get their undergraduate and advanced degrees, and suppose they then did some top-notch research. Then, according to the evidence available, they would still be at a disadvantage compared to people who had done research of equivalent quality and quantity, but who had degrees from high status institutions. For example, Hargens and Hagstrom find that in terms of recruitment to the faculties of top universities (taken as a reward for achievement), prestige of a scientist's doctoral institution is of almost equal importance with the merit of his work.⁴ Similarly, Crane finds that 'among younger faculty, prestige of doctorate rather than past performance is used as a predictor of future performance by those who are responsible for faculty recruitment'.⁵ Caplow and McGee suggest that good contacts (knowing someone in the department, having been there before, etc.) is an important factor in hiring practices. 'Not even as a last resort will [the major universities] recruit from institutions with prestige levels much below their own.' 'A man may, for example, publish what would be, in other circumstances, a brilliant contribution to his field, but if he is too old, or too young, or located in the minor league, it will not be recognized as brilliant and will not bring him the professional advancement which he could claim if he were of the proper age and located at the proper university.'⁶ Turner's distinction between contest and sponsored mobility has been noted as being appropriate in this context: 'Contest mobility is a system in which elite status is the prize in an open contest and is taken by the aspirant's own efforts.' Although the myth of contest mobility is flattering to those with elite status, in reality much more than a small part of mobility is sponsored: 'elite recruits are chosen by the established elite or their agents, and elite status is given on the basis of some criterion of supposed merit and cannot be taken by any amount of effort or strategy.'⁷

At this stage in my search I became fully aware of two major flaws in the favorite argument for continuing in conventional courses. The argument is, stay in the courses now even though you don't like them, because later after you finish you will be able to do what you want. The first major flaw in the argument lies in its assumption that people stay basically the same whatever happens to them. In this specific case, this assumption is that if a student is spontaneously curious and eager to learn at the beginning of a course of study, then this attitude can be put into cold storage until the end of the course, when it can be reactivated in a freer situation. (Perhaps, less generously, the assumption is that these qualities are irrelevant or undesirable.) This assumption, and the argument that follows from it, are certainly not founded upon observations of students. What happens in practice is that students eventually either adapt to course requirements or get out. The conventional course structure operates to destroy the students' confidence in their ability to think and learn on their own, and to eliminate those who refuse to accept external direction of their learning. If John and Graeme were to stay in their course, then when they finished they would certainly not be the same as they would be after an equivalent period in a relatively self-directed programme of study. Nor, it is likely, would they ever be able to recapture the full extent of their original spontaneous enthusiasm after having it stifled for year after year. To say one should do the course now, and do what one wants later, is to obscure the simple fact that what one will want later depends on what one does now.

A second major flaw in the standard argument for staying in the course is that, even after finishing undergraduate courses, there is no real freedom to do what one wants. Instead there is only relatively more freedom (though to the former school student and undergraduate the transition certainly is dramatic). When studying for a Ph.D., postgraduates as a rule are expected to work on safe projects, in which acceptable results can be confidently expected in a reasonable period of time. These 'acceptable' results are almost always uninteresting and unimportant. Speculative projects, that might lead to significant breakthroughs, but which also are more likely to lead nowhere, are discouraged. The pressures working against a free use of creativity remain strong even for the young established researcher, who feels that research leading to quick publication has first priority. ⁸ Perhaps the underlying assumption in the argument for staying in the course is that if one adapts oneself to the course, then after one has been deeply socialised into the norms

and value assumptions of the subject and research discipline, restrictions on research will seem trivial or just only natural.

After pondering these findings, I came around to serious consideration of the third main alternative: drop out and study what one wants. This possibility had been in the back of my mind for some time. There are some obvious problems. An immediate one is that of gaining access to resources for learning. Educational institutions tend to monopolise anything that can be used for conventional learning. Dropping out seems to cut one off from so much. But actually for John and Graeme there would be no real problem in this respect. After all, quitting a university course does not force one to leave the university environment. To learn theoretical physics, there are three primary resources required: books and journals, computing facilities, and knowledgeable people. Access to library and computing facilities is easily arranged through friends or by enrolling in a token subject. And knowledgeable people are usually no less available on a useful basis to capable outsiders than to their own students. Furthermore John and Graeme, as efficient and experienced learners, were used to working largely on their own.

A more substantial problem in dropping out is the converse of the argument for staying in the course. If one does not get a degree with high scholastic standing, then one can not get a scholarship which enables one to be free to do research. One must make a living somehow. If one refuses to take the course now, then there will be no prizes (freedom, money, jobs) later. This is certainly a serious deterrent to dropping out.

An obvious compensation is that, free of the confines of required study, one will be able to get on with highly efficient learning on one's own. John or Graeme have many times the capacity for learning than what is allowed to take place in conventional courses. Released from coercion, they would have a much better chance of making an important contribution to their field of study.

But it is here that the injustices of a credentialed society, discussed earlier, come to the fore. For without a degree, without certification, John or Graeme would have a difficult time indeed getting recognition for their achievements. In the academic sweepstakes having a degree from even a lesser institution puts one a great step ahead of having none at all, almost irrespective of ability and achievement.

But even if John or Graeme could not get as good a job as otherwise, that would not be the end of the world. If they opt to study on their own now, there is nothing to stop them 're-entering'

society later on. It may be only by interrupting one's normal progression through life, and questioning one's needs and motivations, that one can gain the ability to make an enlightened decision about what to do. And surely the fundamental question of what to do is one that must be answered by all of us, whether unconsciously and automatically or through studiously acquired insight.

Balancing all these deliberations, my advice to John and Graeme, if they were to ask for it, would be to quit their courses and learn on their own. For I have decided that this is what I would have done at their age, if I had known then what I know now. (After all, in searching to find an appropriate choice for them, I was really as well trying to understand my own position in the world.) The decision eventually comes down to a question of values. If one accepts the conventional values of society, then it is only logical to stick with the course to the bitter end: the risks in choosing any other path are too great, the rewards too meager. But if one uses different criteria, for example if one considers that one's first obligation is to one's self, the choices are seen from a new perspective:

'Now, what is the significance of life? What are we living and struggling for? If we are being educated merely to achieve distinction, to get a better job, to be more efficient, to have wider domination over others, then our lives will be shallow and empty. If we are being educated only to be scientists, to be scholars wedded to books, or specialists addicted to knowledge, then we shall be contributing to the destruction and misery of the world.

Though there is a higher and wider significance to life, of what value is our education if we never discover it?

We may be highly educated, but if we are without deep integration of thought and feeling, our lives are incomplete, contradictory and torn with many fears; and as long as education does not cultivate an integrated outlook on life, it has very little significance.'

The argument against setting the path of one's own education assumes the acceptance of conventional criteria of success in life: material goods, status, security. Must the restless and endless pursuit of these ends form the basis of everyone's life?

Earlier, I noted that if John or Graeme dropped out (or went to a low prestige institution) and did some significant research, then the probability of this work being recognised would be considerably less than if they did the same research after finishing their original formal course of study. Another important question is, if John or Graeme drop out, are they more or less likely than otherwise to do important

research? And once again, the answer must depend on one's value system. Free of the channelling and socialising effect of the formal courses, John or Graeme would not be as likely to do 'orthodox' physics. They would perhaps be less likely to choose a safe and unexciting research project of the type normally leading to a Ph.D., but instead a more risky and speculative one, with a greater chance of failure and a greater chance of making really significant discoveries.

More important than this, though, is that by following their own interests John or Graeme would be much more likely to begin to question the very significance of doing physics, as physics is constituted today. They might begin to ask, for example, whether understanding physics brings any benefit to mankind; whether physics serves as an ideological prop for the status quo; or what the practice of an enlightened science would be like. These are the sorts of questions that increasingly are being studied in radical critiques of science.¹⁰ And these are the sorts of questions that are denied, obscured, and suppressed by the assumptions that underlie conventional work in physics.

Reconsider now the three respondents from the U.S. and their answers concerning John and Graeme. It is obvious that they did not really consider the possible alternatives. They feel that staying in the course is the only valid alternative, and at least two of them seem prepared to argue that that is the way it should be. They do not consciously recognise that alternative value systems, leading to different preferred courses of action, can exist.

But, it may be objected, surely it is logical, even from the perspective of the conventional scientists, that some attempt be made to cater for dissatisfied students in one's own discipline. But no. Actually many staff are quite happy to see students leave off their studies altogether, even if these are the students most gifted in their own discipline.

'Such a seeping away of competence might seem, at first glance, to be a great loss to the technocracy. But the defaulting first-raters would quickly be replaced by second- and third-raters, who bring with them the advantage of cruder sensibilities and greater docility. Indeed, the technocracy will find itself better served by routineers who are less capable of seeing beyond the official priorities. And being fabulously wealthy, it can easily subsidize the recurrent failures of such mediocrities and glorify their products until they too begin to assume the stature of great scientists, scholars, technicians.'¹¹

Perhaps, too, staff unconsciously realise that by working on their

own, students are unlikely to stay firmly anchored to the conventional way in which scientists perceive the world, and to the limits of this way. For staff, it is certainly a threat to be told, explicitly or implicitly, that the assumptions underlying their lives are not lasting truths or that these assumptions support an oppressive reality against potential alternatives.

A friend of mine once told me that he did not consider that his education had begun until several years after he finished university, at which time he began to learn under his own initiative. The choice to begin learning can be made at any time, but it is perhaps particularly difficult for the undergraduate or school student. At that stage the penalties loom much larger. But also, I think, the rewards can be much greater. That is the possibility that conventional education, by immersing people in its value system, obscures. And that is the possibility that must be grasped by people like John and Graeme if we are ever to have a clear view of a valid alternative society.¹²

NOTES

1. *Newsweek*, January 10, 1972, page 26. Some information in the description is based on a recent letter to me from Dr. Huber.
2. This student-designed course is described and discussed in Graeme Henderson, Brian Martin, John Skaller, and Carol van Beurden, 'Radical approaches to learning physics: some experiences of first year university students', *The Australian Physicist*, October 1974.
3. Albert Einstein, 'Autobiographical notes' in Paul Arthur Schilpp (ed.), *Albert Einstein: philosopher-scientist*, Vol. 1, New York, Harper, 1959, pp.17,19.
4. L. L. Hargens and W. O. Hagstrom, 'Sponsored and contest mobility of American academic scientists', *Sociology of Education*, 40, No. 1 (1967), 24-38.
5. Diana Crane, 'The academic marketplace revisited', *American Journal of Sociology*, 75, No. 6 (1970), 953-964 (p.953).
6. Theodore Caplow and Reece J. McGee, *The academic marketplace*, New York, Basic Books, 1958 (p.112, pp.128-129).
7. Ralph H. Turner, 'Sponsored and contest mobility and the school system', *American Sociological Review*, 25, No. 6 (1960), 855-867 (p.856); a good discussion of the typical intrusion of social and cultural values into the evaluation and control process in science is to be found in Stuart S. Blume, *Toward a political sociology of science*, New York, The Free Press, 1974, pp.77-87.
8. M. J. Mulkay in *The social process of innovation: a study in the sociology of science*, London, Macmillan, 1972, argues that social pressures determine that most scientific innovation is by new recruits and by senior workers with established reputations. Newcomers to the field have no reputation to lose by following speculative paths, while scientists of established reputation have little to gain from conventional work. But this perspective does not give any reason to doubt that there are strong pressures against originality and nonconformity at all stages of the scientific career. For example Mulkay discusses 'The existence of strong pressures towards intellectual conformity in science' (p.19).
9. J. Krishnamurti, *Education and the significance of life*, London, Victor Gollancz, 1955, p.11.
10. See Herbert Marcuse, *One dimensional man*, London, Routledge and Kegan Paul, 1964, especially chapter 6, and Jurgen Habermas, *Toward a rational society: student protest, science, and politics*, London, Heinemann, 1971, chapter 6.
11. Theodore Roszak, *Where the wasteland ends: politics and transcendence in postindustrial society*, London, Faber, 1972, p.70.
12. I would like to thank Dennis Sams for valuable comments on an earlier version of this article.