Save science or scientists' interest? And why?

Y. P. Joshi

The guest editorial 'Saving Indian Science' by Rao in *Current Science*[1] was interesting not because it presents the case of scientists effectively, but because it initiates a debate on why science should be supported and how much. Such a debate is going on even in the technology-rich West, where science has been reigning supreme for the last two centuries, and variety of comments have appeared recently in the editorials and other columns of some science journals and magazines[2-5]. It is painful to accept fund-cuts, and for that reason a large majority of our scientists would definitely be sharing Rao's views and disappointment. They would not hesitate in joining him to 'save science', attempting to convince the public with arguments based on rather ideal assumptions. But the reality is not that simple and all is not well with our scientific community. In this respect, Rao's arguments are one-sided and incomplete. He has failed in making an effective self-assessment and has avoided self-criticism.

Why science at all? Broadly speaking, we have two distinct reasons to defend science. The first is of universal nature applying to all fields of human knowledge. Exploring the objective world and beyond that by all methods at our disposal—observation, argumentation, imagination, etc.—has been undoubtedly the essence of human civilization. Science with its modern formal structure happens to be just one of the many established fields of knowledge and endeavour. It is an historical fact that creativity in all forms—be it in arts, literature, science or philosophy—has been and continues to be encouraged and supported to variable extent by government agencies and other organizations. In the past and in many places, the process of support may not have been as formal as it is today, nevertheless it was there. Perhaps there is not much to say against the encouragement that science is continuously receiving, but there is a very pertinent question that must be raised: To which extent should it be supported in terms of physical resources, particularly when it is merely for the sake of expanding human knowledge? The answer must take proper consideration of the place and the society where such support is being sought. Obviously this answer cannot enjoy universal acceptability. Thus what can be reasonably supported in the US may not necessarily deserve a support in India as well. That the affordability of a society is of prime importance has to be admitted and advocates of science for knowledge must explain how that knowledge is relevant to the society and how that would be accepted and assimilated by it. If a piece of knowledge remains confined and enjoyable to a small group of individuals and at the same time if it is taxing the society, then not strong arguments can be found to defend the venture. I find the following words of Pippard[6] worth citing in this connection:

> To opt out of the society by immersing oneself in research projects to the exclusion of other duties is not a course of action to be recommended to all. There are indeed some who can help best by cultivating their own gardens, and being content with a very small plot at that. But it is surely going too far to pretend that in times of trouble and change it is specially meritorious to concentrate on what is rather easy and agreeable (for those who can do it all), the pursuit of knowledge for its own sake without giving thought to whether anyone really wants that knowledge and if so, for what purpose. Do not misunderstand me—I mean no disrespect of knowledge that is sought in the face of hazards and disappointments—*I am only deploring the halo that simmers around all research, however trivial, as though measuring the resistance of a piece of wire were more ennobling than roadmending*

There is indeed a second reason, and more important at that, to support science, which in its broad sense includes science-based technology. Perhaps this is the reason which Rao is trying to emphasize. I am of the view that scientists are becoming more like religioners who make all attempts to defend their faith and prefer not to put it to scrutiny. At times they go to the extent of becoming sentimental. Rao's words 'We need science for survival, science has to be protected for its own sake' in fact reflect the deep emotional attachment that the majority of scientists develop to science in the course of their professional careers. They claim to be objective in their pursuit of knowledge, but they suffer from a marked degree of subjectivity in assessing the importance of science in the context of social welfare. It is their conviction that *the more science we do the more the welfare of the society is guaranteed.* The industrial revolution of the last two centuries, based on scientific progress, has been perhaps the main reason behind this conviction. The world population is undoubtedly impressed by the contributions that science has made to the developmental process and well-being of the human society and they definitely feel obliged to the scientific community. Admittedly, science has helped humankind in achieving what was otherwise seemingly impossible and it has added to the comforts of life. Unfortunately this fact has made the scientists less humble and more insensitive to the various problems of the particular social fabric to which they belong. Instead, they have become more exploitative.

The terms exploitative and insensitive used above deserve elaboration. In my opinion there are some questions that could be asked in respect of the social problems encountered locally in a closed society or globally on a wider scale. Do scientists feel a concern for these problems and get consciously involved in solving them? Do they realize that solving any of the present-day problems does not necessarily need more science but a better utilization of whatever science we have with us? Do they take steps to propagate the cultural aspects of science so that it brings a change in the attitude, outlook and behaviour of the individuals of a society? Do they devote their time also to educate the masses with their scientific findings, so that the latter get

enlightened and become more appreciative of the knowledge being generated? And in the end, do they realize and openly admit that science does not and cannot solve all problems and that, at times, it even creates problems? The answer to these questions would be mostly in the negative; and I consider this an indicator of the insensitivity on the part of the scientific community. On the other hand, projecting science as the saviour of mankind and a panacea to the physical problems faced by humanity is, in my opinion, an indicator of their exploitative attitude. This exploitative attitude is further reflected in their demand for more privileged position in the society and for priority access to the limited available resources without giving a serious thought to whether these resources could be more beneficially utilized to fulfil other pressing and immediate needs.

It appears that scientists avoid recognizing that in solving one set of problems, science-based technology often creates newer more serious problems. Invention of the atomic bombs, chemical weapons and biological warfares, etc. are known and oft-quoted instances of misuse of science, and there is no need to attach much importance to these in the present context. To me these are reflections of the aberrations in the behaviour of certain organizations and nations. There is always the possibility of deliberate abuse of science, and I would lay no blame on science in such cases. But I consider it serious when the problems arise due to the ignorance on the part of the scientific community. Humanity and the rest of nature around it form such a complex system that it is almost impossible to predict the long-term damaging consequences of some technological breakthroughs, particularly of those which find immediate and large-scale application. This is because not all the relevant details of this system are manifest at any moment, and one has to wait for some time to notice the appearance of these consequences. And when they start signalling their presence, it often becomes hard to arrest them, mostly because the response of the fellow human beings is often not encouraging and cooperative. To make the point clear, I cite the example of the ozone depletion that is being so much talked about at present. The apparently inert chlorofluorocarbons (CFCs) were discovered some sixty years ago and put to common use without being suspected for any ill effects on the atmospheric system. It was only much later, about twenty years ago, that their reactivity with laboratory ozone was discovered and the world community started paying attention to the possible ill effects the atmospheric ozone may be suffering from, the CFCs that had already escaped to the higher altitudes of the atmosphere. Did anybody dream of the consequences of the CFC technology when it was invented? Take another example, that of the automobile revolution, which has affected our life-style to such an extent that today we cannot imagine living without it. For the individual humans, it has proved of immediate advantage, for the globe it has brought the problems of pollution and rapid depletion of fossil fuel. We are now worried how to continue with the present fast life-style when the petroleum sources are exhausted.

In fact the origin of many of today's problems, like pollution, green-house effect, ecological imbalance, and loss of natural resources, can be traced back to one or more of the technological advancements. It would be unfair to blame science alone for these. In fact, these have cropped up because the world population could not practise self-restraint and wanted a quick exploitation of these developments. Unfortunately the scientific community had failed to realize that whenever a new technological invention becomes available to the masses, the latter take no time in getting carried away by the immediate benefits obtainable from that advancement. It often takes no time for the technological advancement to get translated into a commercial venture and thereby to become an integral part of the local or world economy. The scientific community often fails to assess the long-term implications of a new technological development, to warn the society of its possible adverse effects on the environment, and to suggest ways of optimizing its utilization. To clarify this point, I refer again to the case of automobile revolution, which added so much comfort and convenience to our private lives that perhaps every individual, who could afford one, went out to opt for a petroleum vehicle, using it even in those situations where it could have been very well avoided. The results are the petroleum crisis and a variety of pollutions. The scientific community could have regarded such problems as a proof of the fact *that unrestricted exploitation of any technological development may sometimes turn out to be dangerous.* They could have therefore come out of their research cells to educate the public for practising self-restraint and to avoid indiscreet use of the comforts created by modern technology. But instead of doing this the scientific community is conveniently exploiting the situation to justify more funding and to acquire importance in the society.

It might appear from these remarks that I am against scientific research and technological development. This is really not so. There is no denying that a number of tasks fall outside the normal capability of the human beings and only scientific progress can accomplish these. What I want to stress is that there are numerous such problems, particularly those created *inadvertently* by science, that cannot be solved by science itself. The problems of various types of pollutions, impending exhaustion of natural resources, energy crisis, ecological imbalance, and population explosion fall in this category. (Ironically, population growth itself is the result of modern scientific progress.) The notion that more and more technology can succeed in solving these is essentially a myth and it would be wishful thinking to hope that some day we will have a technology which is free from any by-product problems. Let us admit that there are two mutually complementary approaches to solve these problems. The first is to bring awareness of these amongst the masses, to educate them against the possible hazards of injudicious exploitation of modern technology, and to cultivate in them a scientific outlook and a sense of responsibility. The other approach is to look for more advanced and sophisticated technology. Unfortunately, the latter fails miserably in many cases. For example, it cannot stop the depletion of most of the minerals and rare elements, unless we introduce the concept of recycling and seek peoples' participation to make it feasible. The reason is understandable: Technology generates consumerism, and consumerism results in the rare elements becoming irre-

coverable in the absence of recycling. The problem of population growth is a second example which cannot be tackled by modern science. There is no doubt that technology may give us newer methods of population control, but no results can be achieved unless the outlook of the individuals of the society changes. Consider the case of pollution. I cannot hope of a reduction, for example, in the air and the sound pollution of an urban area, unless people start contributing individually by not driving in the crowded areas. These are instances which suggest that *technology, in spite of its continued refinement, cannot prove helpful, unless it is accompanied by a corresponding behavioural change on the part of the society*. Has the scientific community taken this fact seriously? Would this community ever pause for a while to study how a new technology would be received by the society and how it would be used or misused? Scientists cannot have the freedom of shirking from this responsiblity. But it has become a fashion to lay stress on more and more scientific activity without giving due importance to this point.

If we look at the cultural, economic and political turmoil that the world is facing today, then we may conclude that despite the tremendous scientific progress we have made, we cannot claim that the human society is happier and more content today. Is it that our science so far has been lacking and that we have to do science quicker to settle the world problems? Perhaps not. There is something more serious, which the scientific community must pay attention to, if it boasts of its obligations to the society. In this connection I find it interesting to ask myself a few questions: What is the optimum speed at which science should be pursued? Should we move faster and faster to achieve everything overnight and get impatient to gather all its fruits within no time? Should we ignore the cultural aspects of science? Should we forget that it has to be used as a tool for a social reform, and for educating them to find a nobler and satisfying purpose in living itself? And should we regard science purely as a means for physical well-being and a basis of modern economy? I feel scientists should have addressed these questions before claiming that their pursuit of science is more for the social good and less for their individual benefits.

These remarks are of general nature. Let me now refer to some points that are pertinent in the Indian context. To begin with, I refer to Rao's remarks: 'I am seriously worried by the widening gap between us and the advanced countries.' He refers to the gap in the field of science. But can he mention those fields in which we are not lagging behind — lagging too far behind really? In fact, the gap in some other fields is more shocking than in science, and it would be too selfish on the part of our scientists to express concern for science without referring to the grave situation in these other fields. In this connection, the primary education and literacy deserve a special mention. It is an interesting and noteworthy fact that many smaller nations of the world are far better than we are as far as social well-being is concerned. It will be deceptive to claim that the overall social progress of these nations had been achieved by putting special emphasis on scientific research. In fact many of these nations are so small that their limited resources would not permit scientific research on many fronts. Yet they are far better-off. The reason is perhaps that we are lacking in proper management of resources and man-power. Our society is plagued with missing sense of responsibility, accountability and work-culture and there is no such leadership that could set for the goal-oriented activities with properly defined priorities and effective resource management. I am afraid to mention that the scientific community is no exception. When our science-managers lay stress on scientific research, they ignore that most of our research is done simply for the sake of research and lacks in purpose.

It is admitted by all that science is international in character. Scientific knowledge sees no national barriers and can become available to the interested parties in almost all parts of the world. It is the resulting technology which is now being confined to the geographical boundaries of that nation where it is developed. This is now happening purely for economic and commercial reasons, so that the business interests of a nation are served with maximum material gains. In view of this fact, there are two courses open to us: The first is to pool our resources and engage the scientific man-power in developing and advancing newer technology. The second is to pay for it and depend on the developments that are taking place elsewhere. It appears that the majority of scientists, in principle, are in favour of the first and in that respect are emphasizing the *role* of our scientists and the need for the material support to them. In fact the encouragement and support that science has been receiving in the post-independent India is based on the simple argument that it is vital for the progress of the nation. This argument has received so much respect that today we have become the third country with the largest scientific man-power. Yet this scientific man-power has failed to pay its returns, and the country is helplessly opting for the second course of action stated above. The fact that we are borrowing technology from outside and paying for it suggests that this scientific man-power has proved largely irrelevant. There must be serious reasons behind it.

It is perhaps not proper to compare ourselves with the advanced countries in order to justify scientific research and the demand for more government support for that. It has to be clearly admitted that our socioeconomic conditions and cultural background are very much different and our priorities cannot be the same as those of these countries. We cannot therefore afford to regard those nations as models to follow blindly, and recommend any scientific research without properly assessing its significance in respect of our specific needs. It is not difficult to identify problems which may interest some or many members of our scientific community but whose results may have little or no relevance to our social objectives. I am strongly of the view that research for the sake of knowledge only can be definitely patronized through moderate support, but liberal funding for these in a poor country like ours cannot be justified. *It might prove self-satisfying for the scientists to indulge in scientific research with the objective of seeing themselves on par with the scientific community of the advanced countries. In so doing they may cultivate the false notion of having obliged the nation by raising its respectability in other countries.* Unfortunately, there are a number of factors which contribute to the respectability of a nation, and unless there is a parallel progress in other fields, scientific research alone cannot play a significant role, particularly when it is pursued without recognizing the real needs of

the nation and without judging how this research proves to be paying.

Before arguing strongly for more support to scientific research, the Indian scientific community should have made a serious self-assessment of its achievements during the last few decades. It is conceded by many that despite the significant growth of the scientific manpower of our country, there is an overall fall in the scientific achievements compared with the rest of the world. Except for a few isolated successes, we have not much to our credit. Poor funding and paucity of other resources may have had a significant role to play, but it would be wrong to hold them entirely responsible. In my own reckoning, one of the factors important in this respect has been the lack of vision, originality and courage. To me it appears that our scientific community has almost always been tamed by the West. By this I mean that we have been lacking in an initiative and look to the West for inspiration, guidance and evaluation of scientific research. Why is it that newer ideas are not emerging in India? I have not prepared an exhaustive list of instances, but I can cite a few examples. In the physical sciences, some new scientific results of rather unusual nature were reported during the recent past, which attracted the attention of a relatively larger audience the world over. These include, among others, the discovery of quasicrystals, fullerenes, the high-T_c superconductors, the quantum hall effect, the string theory, and the now-forgotten cold fusion. None of these was first reported from India, why? The reason is not the lack of facilities, for soon after their being reported, results of investigations started pouring in even from our research laboratories. This means they had been just waiting for the ideas to percolate to them from the West. This indicates that our scientists, exceptions apart, do not have the courage to practise originality and to take a research initiative on their own. In fact, the domination of the West in the field of science had had such strong psychological impact on us that we were reduced to intellectual dwarfs. This phenomenon continues to take place and today we look to the West as trendsetters and as guides to tell us what is worth investigating. This weakness of ours can be clearly seen in the recent change in our attitude to the traditionally Indian subjects of Yoga and Ayureda (of interest to medical scientists), and the Sanskrit language (of interest to computer scientists), which occurred when these started receiving the attention of the West. Indian scientists' tendency of attaching extra importance to visits to the West and to publications in *foreign* journals supports these views. One may doubt these conclusions, but then do these observations mean that our scientists find it safer in their own interest to do routine research mainly to duplicate what is being reported in the West?

Before setting out to express our concern for science and to win public favour to 'save' it, we should have better examined the real motivation with which scientific research is being pursued in our country. There are a variety of possibilities. Scientists are generally not in the habit of giving a serious thought to the question of why do science and that too how much and at what cost. For most of us doing science is to a large extent a professional compulsion and to some extent a fashion of modern times. The desire of seeing one's name in the print, of getting recognized as an established scientist, of having a say in science policy decisions and funding, etc. are perhaps the most important factors behind one's involvement in science research. Since career promotion and professional advancement now depend very heavily on the number of publications, our interest is gradually getting confined to increasing the list of these, with not much concern for the quality and contents. The research problems are not picked up on the basis of some predefined priority, but on the basis of how they would save an individual's interest best and lead to quick and guaranteed publications. I am definitely not against the freedom of our scientists of enjoying themselves in creating and expanding knowledge. Nor am I against an individual's right of safeguarding professional and personal interests. But I would certainly like to note that for the majority of us research activity has become an enterprise aimed at establishing ourselves within the country and sometimes outside rather than meeting a national objective. Then will it be fair to ask for bigger and freer support when in return we are willing to contribute little significant in the national context? The fact that science is international in character and that we can only follow the trends being set elsewhere can serve as an excuse and consolation, but it certainly cannot be regarded as a justification, particularly when we are accountable to the nation and not to the international community.

Much of what has been said above deserves serious debate and that debate should not be confined to the scientific community alone. There is no denying that this community will defend its position with arguments that are woven around certain ideal notions and therefore sound very convincing. But there are certainly some real-life observations which make the scientists' case rather vulnerable. I should discuss a few points we all have been conveniently avoiding to mention. Let us agree for the moment that they have to create knowledge and put it in published form, hoping that someday it proves its worth. But in addition to that, what more is expected from the scientists? This is a natural question that should arise in our minds. This question is important because in its answer would be reflected their real concern for the society. The first thing the scientists should have done, in my opinion, is that they start making a realistic assessment of what they have been doing. To project any and every scientific research activity as of vital importance in the national context and to make exaggerated claims in respect of the returns that a particular piece of work would be paying is something that should be stopped outright. The high-T_c superconductivity offers an example which was described as of immediate and irresistible significance that could change the technological scenario of the country; and with these arguments crores of rupees were poured in its research. What are the end results now? Similarly, crores of rupees have been spent on the proton-decay experiment; what is the outcome? According to some recent news item, our scientists are planning to send a space-vehicle to the planet Mercury. What would be the gains obtained? *Such costly projects may satisfy the ego of the scientists, but it is doubtful if they serve the interests of a larger section of the society.* We blame the politicians for lavishly spending money on activities which are neither productive nor directed to social welfare. We all have been criticizing the unduly large expenditure on government administration. What about the expenditure in the field of science? Are we spending

judiciously? Is it not time that we voluntarily stopped demanding huge sums for projects which are not even remotely connected with the welfare of the society, even though they appear otherwise fascinating? Should we not be serious in identifying more relevant projects, and should our scientists be not willing to divert their efforts to these, even when they do not fall in the fields of their direct interests?

Still more serious is the misuse of funds granted for a given project. Optimization is a highly used technical term in scientific literature, but optimal use of funds is a concept little known to our scientists. In recent times there has been a noticeable growth of an unhealthy attitude of collecting large funds in the name of fashionable and seemingly useful projects and then utilize these on items outside the original terms of the grants. In fact funds are becoming symbols of status within the scientific community; and more and more scientists are joining the mad race of fund collection to establish their leadership, resourcefulness and importance in science management. And then they do not hesitate in spending money on equipment and other items which remain underutilized and sometimes even unutilized. The concept of auditing is practically missing, and progress reports have been reduced to pure formalities essential for continuation of grants. But there is no meaningful effort on the part of the science managers to evaluate the real progress in a research project. I have yet to hear of grants being stopped to the recipients due to an unsatisfactory progress. Once grants are in hand, the use or misuse becomes completely a prerogative of the receiving scientist. Can we then claim that we have been sufficiently sincere in the disbursement of funds and in monitoring their utilization?

That our scientists' interest in the good of the society is largely of superficial nature is reflected in their concern for the current state of science education[7]. A large number of scientists work in academic institutions and they are supposed to be educators in the first place. Scientific research in their case must be seen as an activity of an essential import in the process of education, particularly higher education, but it is certainly not a substitute of their teaching assignment. In spite of the significant growth in our science research, there has been a noticeable decline in the standard of education during the recent past. More and more of our scientists in the universities and colleges are showing apathy to teaching willingly avoiding interaction with the students. Laboratories are getting neglected and sometimes remain unattended. A number of institutions are known to be lacking in the basic amenities essential for laboratory teaching. It is ironical that no funds can be made available to these laboratories, even though research grants can be freely sanctioned to the scientist teachers of these places. The distinction between scientists in research institutions and those in teaching institutions is being gradually lost, with teaching activity being rendered subordinate to the research activity. It is now common for our scientist teachers to consider research workshops, conferences, meetings, etc. to be first-priority items and regard the teaching as a leisurely activity to be undertaken at convenience. It is not the other way round that we put teaching on top and see that the other activities do not interfere with it to the extent of damaging it. Has anybody given a thought to this? Scientific research in any academic institution is encouraged on the basis of this ideal argument: Creation of knowledge and its impartation to students should go hand in hand. Unfortunately research expertise of our scientist teachers remains irrelevant to the students, particularly at the undergraduate level. The teachers have willingly failed in breaking monotony and stereotypy in teaching and in introducing novelty and variety. Who has made an assessment of their contribution in this direction? In the field of education the teachers could have done a lot. They could have produced low-cost textbooks and other literature for the use of the Indian students, so that our dependence on imported books is reduced. In fact they could have contributed in numerous other ways. All these are socially relevant activities. Admittedly these are less paying in the international research market than the publications in archival journals. Is that the reason of the scientists' indifference to science education? In fact, this apathy extends even to the doctoral degree programme of many institutions. Mediocrity is being encouraged not by outside agencies but by the scientists themselves. Ph D's are being awarded to whoever joins the race, notwithstanding the quality of work. This has resulted in the enlargement of the size of scientific community, but has added little to its capability and relevance. Who is to blame?

It was stated earlier that science has its own strong cultural aspects and that it is an effective tool to bring reform in the thinking and behaviour of the masses. Unfortunately, our scientists have failed even on this front. They have not considered it their responsibility to teach the masses how science and technology have to be used. They have been constantly ignoring that an advancement in technology which is not coupled with a corresponding social change may result in problems. Are they willing to define their roles in this respect?

Are we really selling science as if it were a commodity to be consumed by the masses and as if in their doing so our business interests are safeguarded? Somebody has remarked[2], 'The promise of science—a miracle cure—serves the politicians, who are always looking for patent medicine to sell to the public, and it serves scientists, who understandably seek to preserve their special position in our culture. But it may not serve society as advertised.' What is then the real worry of my fellow scientists? The fear of losing their privileges? Perhaps they do not know that our great nation ranks simply 147th amongst the countries of the world as far as overall development is concerned. Is it not an irony and a shame that the world's largest democracy has *almost* the lowest literacy, lowest per capita income and poorest social welfare schemes? Science is surely not to blame. But then admittedly it has not helped much. And it will not help in future either. Something more serious than science is needed: who is to worry?

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John Bonner who gave the 1993 Gandhi Memorial Lecture (published below) has created for himself a niche in his field of research. He is considered the world's greatest authority on Slime Moulds. He was the Visiting Raman Professor of the Indian Academy of Sciences (IASc).

For over 50 years in his researches he has always picked the right question, designed incisive experiments and has presented his findings in articles which are models of scientific writing. IASc has brought out a volume of his selected papers, which has received rave reviews. Slime mould amoebae are living micro-organisms that periodically gather together to form macroscopic fruiting bodies. John Bonner sees the universe in this micro-organism. It is in this philosophical and social vein that he gives the Gandhi Memorial Lecture.

Editor

Dividing the labour in cells and societies

J. T. Bonner

In all collections of living entities, from cells within an organism to individual organisms within a society, the greater the size of the group, the greater the division of labour. Yet there are important differences in how the labour comes to be divided in cells and in societies.

I felt enormously honoured when asked to give this Gandhi Memorial Lecture, but at the same time I was struck with awe when I considered what I might say. How can I connect my modest lifetime interest in biology with the ideas and thoughts of a giant who did so much not only to change India, but to change the whole world. The answer is that I can only fail and this lecture will be testimony to that failure. However, I shall try very hard to make it an interesting failure!

My intention is to discuss a grand and important generalization that applies to all living things. To state it simply in one sentence, it is that at all levels of life, from cells in a multicellular organism to individual organisms in an animal society, there is a division of labour, and the extent of that division of labour depends directly upon the size of the community. This is an aspect of the organization of nature which has interested me for many years, and here I would like to share some of those thoughts with you.

My plan is to begin with examples from the living world that show both a division of labour, and a correlation of the extent of this division of labour with size. I shall begin with lowly slime moulds and end with a discussion of human societies.

The important question is why does one have such a relationship: that is the real purpose of this lecture—to explore the 'why'. I will argue that this relation of division of labour to size is not some mysterious law of nature that so far has defied identification and is in need of revelation. Rather I will urge on my listeners the straightforward idea that it can be explained in the simplest way, using well-known principles. There will be differences in the details of the relation at different levels; what happens among cells is not identical to what happens in societies. Yet despite those differences there are certain things that are the same at all levels, and this will be the main object of our quest.

Finally, there is always the hope that any insights into something as fundamental as the relationship between size and division of labour may help us to understand our present day human condition. It would, however, be misleading to imply that such searchings will provide solutions for our troubled world, but perhaps they can give some insight, some understanding, and understanding is the first step in all human progress.

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My initial interest in the size-division of labour question came when I started as an experimental biologist. I was interested in embryology, in how animals develop, but I was dismayed that animal embryos, especially amphibian embryos, which were the main object of study of embryologists at that time, were so complex. In my search for something simpler, I was very lucky to find little known organisms called cellular slime moulds, and I began my work on these many years ago as an undergraduate.

These minute organisms live in the soil[1,2]. They feed as separate amoebae and in many respects, both as to size and appearance, they resemble our white blood cells. They feed on bacteria and after they have cleaned an area of food they do a remarkable thing; they stream together by aggregation to form multicellular masses of cells, usually of about ten to a hundred thousand cells (Figure 1). The multicellular structure has a front and hind end, it is covered with a slime sheath and in all ways behaves as an individual multicellular organism. For instance, this 'slug' will go towards light and orient in heat gradients. It is very small—a large one will be a millimeter long and something in the order of a tenth of a millimeter in diameter.

After a period of wandering, this slug will right itself and send a small fruiting body up into the air. It does this by having the anterior cells form a stalk by a sort