Wallenberg Prize Acceptance Speech. The Future of Biology: Reason for Concern?

Your Majesties, Your Excellency, distinguished guests, ladies and gentlemen: First of all, I wish to thank the Wallenberg Foundation for the high honor of selecting me as the winner of the Marcus Wallenberg Prize of 2002.

I note that the stated purpose of the Wallenberg Prize is to promote interest in and the advancement of the forestry sciences. The forestry sciences, like all sciences, have both a component of pure-basic science and a component of applied (engineering) science. Applied forestry has a secure future, at least in the medium term, because there are commercial incentives that drive advances in applied research. But in the long run, the advances of *all* applied science are preceded by the knowledge base generated by pure-basic science. Hence, applied research will eventually falter and stagnate without advances in basic sciences. The basic biological sciences, without a doubt, have made important contributions to forestry. So I want to use the forum offered to me by the Wallenberg Prize to share with you the major concerns I have for the future and health of the biological sciences.

Molecular genetics has transformed the biological sciences. These transformations are sweeping. Ironically and paradoxically, these transformations are causing serious damage to biology. Why, you might ask, do I think there will be serious damage? Damage may result because molecular genetics is bringing about changes to the biology curriculum in our universities. And these curriculum changes will seriously weaken the very knowledge base that has brought the biological sciences to the point we have reached today. I will share with you my thoughts in more detail. Let me start out with a parallel example. Let me start with an example where advances in science have gone forward without harmful effects to its fundamental knowledge base. I give you the example of physics.

PHYSICS

Physics has a long history of conceptual developments that have spawned new and exciting subdisciplines. We can trace modern physics back to Newton and Galileo. Galileo pioneered an observational and experimental approach to physics. Newton extended this experimental approach and bound the whole into the theoretical framework we now call Newtonian physics. Newton laid the groundwork for celestial mechanics, for structural mechanics, for statistical mechanics, and ultimately, it could be argued, for thermodynamics. The discoveries of Newton ultimately were supplanted by new breathtaking discoveries. Examples of the discoveries that followed include relativity theory, nuclear physics, and quantum mechanics.

These new discoveries changed the structure of our universities. Let me explain how. The young scientists pursued the "hot" fields in our universities and private laboratories, and these young scientists replaced the older traditional physics professors on the faculties of our universities. But these changes did not result in the loss of the old knowledge base in physics. Why is this so? Part of the reason is that Newtonian mechanics is still quite useful even though inaccurate and hence technically wrong. Newtonian physics is still good at predicting everyday events on earth. It is even good enough for NASA to plan trajectories of spacecraft in our solar system.

The other reason the old knowledge base remains is that there is a mathematical continuity that passes through all of the history of physics. The mathematical continuity binds together physics from Galileo to modern times. So students of modern physics follow an apprenticeship in our university curriculums. During this apprenticeship, our students learn the fundamentals of calculus and differential equations

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that bind together the concepts of Newtonian physics. These must be learned first *before* the student is equipped with the skills needed to learn the advanced mathematical theory that is required for such fields as quantum mechanics, high-energy physics, astrophysics, etc. Hence, physics has advanced with a coherence of thought in the modern age of science. This coherence of thought has naturally structured the modern physics curriculum in our universities.

We did not throw Newtonian physics out of our curriculum 50 years after the advent of quantum mechanics and relativity theory. In theory, quantum mechanics could be scaled up to understand the evolution of the entire universe but Newtonian physics is still useful in helping us bridge the gap between quantum physics and astrophysics.

PLANT BIOLOGY VERSUS PHYSICS

Now, please allow me to suggest an analogy. I would argue that quantum physics is to astrophysics what molecular genetics is to the ecology of all organisms on the earth. The essential difference in the history of biology versus physics is this: Fifty years after the advent of molecular genetics, we have eliminated from the curriculum of almost every university many essential fields in plant sciences such as taxonomy, plant anatomy, and whole plant physiology. We have still got ecology but it is somewhat weakened by the diversion of funds to molecular genetics. If you let me carry the analogy further then I could say: These traditional fields of taxonomy, anatomy, and physiology are like the Newtonian physics of plant biology! We cannot afford to lose these fields if we ever hope to bridge the gap between how genes work on the one hand and how the ecology of the world functions on the other hand.

Once we are past the excitement of working out the genetic code of whole organisms and once we are beyond the excitement of figuring out what proteins are coded by each gene, we still will be stuck with a very complex problem. I am talking about the problem of trying to figure out how this rich soup of proteins acts together to produce specific organisms. And I am talking about how these proteins determine all the details of the intricate structure of complex organisms. We must understand the structures of organisms and how specific structures result in specific functions. And we must understand how minor changes to structure (which are ultimately under genetic control) might enhance or detract from its functionality. We have learned a lot about issues of structure and function from plant anatomy and whole plant physiology, and there is much more to learn. The unfortunate thing is that we have virtually eliminated the traditional fields from our university curriculum at a time when they are needed more than ever!

Is it okay to let these fields lie dormant for a few decades? If we allow these fields to die for a few decades, will not future generations of molecular geneticists access this old literature and use it when needed? Recent history suggests that this would not happen. Molecular geneticists view any literature more than 5 years old to be out-of-date and not worth reading!

Let us take the limited example of membrane biology. Membrane biophysicists have elucidated cell membrane function. And these traditional scientists have studied the mechanisms of action of many proteins embedded in cell membranes. Many important advances have been made over the past 50 years, and some Nobel Prizes in physiology have been awarded for the work on membranes. Molecular geneticists more recently have worked out the genes that code for membrane components and have modified genes to change the structure of membrane proteins. Molecular geneticists are repeating experiments done up to 50 years ago not realizing it has been done already, and in many cases the repeated experiments are not rigorously executed! This repetition of past work is wasteful of the limited financial resources of science and repetition of past work is not an efficient way for biological sciences to advance.

To be fair to molecular biologists, I have to remind the audience that genomic techniques are quite complex. Hence, it is unreasonable to expect that scientists proficient at genomics will also have time to keep abreast of techniques in physiology from the membrane to whole organism level. This suggests to me that collaborations between specialists at the different levels of biological integration would be more efficient than for either group to be working independently. But this will work only if traditionally trained biologists are still in our universities.

AND ON TO THE FUTURE

So what do we do to curb the zeal of the deans of science in so many universities who want to appoint yet another molecular geneticist as a replacement for the next physiologist or anatomist about to retire? We have to tell them that molecular genetics is, of course, a good thing but that too much of a good thing is bad for biology. We have to maintain a diversity in biological disciplines that is commensurate with the diversity of biological organisms! But how do we do this in the best possible way so as to foster interdisciplinary collaborations in biology? It is not adequate to just fill up a campus building with a wide variety of specialists and hope that they will start working together. Anybody who has spent part of his or her career in a biology department will know that collaborations rarely emerge from mere cohabitation in a building.

Of course, we could be satisfied with just ensuring the continuation of these traditional fields. We certainly need them. Let us take the example of the INRA, which is France's federal agency for agriculture. Much good work has been done in the INRA integrating traditional disciplines to understand and model for the behavior of agricultural organisms. But within the next 10 years 40% of these scientists will retire and French universities are no longer producing replacements for these essential scientists. Very similar and alarming statistics apply to the United States and other countries. We have lost the capacity to train the number and type of biological scientists we need! But we need to do more than just ensure the continuation of the traditional subjects.

We need to put anatomists, morphologists, taxonomists, physiologists, and other traditional biologists in close proximity to molecular geneticists *and* we have to provide good incentives for all of them to work together. We need these people to be constantly talking together and working on collaborations to integrate studies at multiple levels of organization from molecular genetics to physiology to ecology.

A very important challenge in the next decades will be constructing an interface between genomics and whole plant or animal ecophysiology. If no more scientists still exist in anatomy, taxonomy, physiology, and environmental sciences, this essential process will not be possible. The INRA is one of the very rare national institutions in Europe that still maintain all these different specialists.

The best way to foster collaboration is to finance research, which requires multiple levels of integration in order to receive funding. We also need to fund scientific meetings and workshops to encourage scientists from multiple disciplines to talk together and to work together. We need to train a new generation of traditional biologists to be good at what they do, whether it is anatomy or physiology or whatever. And we need to encourage the next generation to seek out collaborations with molecular geneticists. In my view, this level of collaboration will be best for all the fields of biology. Collaborations also will result in high levels of synergy and advancement of biology as a whole.

Finally, I want to raise the question of the benefits versus the dangers of genomic research. We now have the intellectual power to make significant changes to the genetics and hence structure and function of all organisms on earth. But the potential benefits of such manipulations also pose great dangers with both ecological and moral dimensions. Clear parallels can be drawn between genomic research and atomic energy research in terms of benefits versus dangers.

Time does not permit me to explore these interesting issues, but let me just point out that the potential dangers of genomic advances in agriculture have prompted European governments and regulatory agencies to place a moratorium on the introduction of genetically manipulated organisms into European agriculture. I presume this happened because traditionally trained biologists warned our governments that we need time to evaluate the potential dangers. The current patent system protects the profitability of genomic manipulations in the agricultural and medical sciences; hence, we might want a scientific advisory community that provides an oversight of the genomic industry that is independent of the profit motive. It is therefore paradoxical to look into the future to see that our universities are no longer training the independent biologists we need to provide this vital advice! This issue has to be addressed before our universities lose the capacity to train traditional biologists.

We have a long way to go and it will be interesting to see what happens over the next few decades. I wish to thank the Wallenberg Foundation for providing me a suitable forum and occasion to elaborate my beliefs. I have never had an opportunity as good as this one, and the opportunity to expound my thoughts is as important to me as is the honor of receiving the Wallenberg Prize of 2002. The Wallenberg Foundation could play a useful role in this process of advancement and integration of the biological sciences.

Thank you.

Melvin Tyree