Interdisciplinary Research: What Makes It "Interdisciplinary?"

Scientific literature is sprinkled with popular, but ill defined, words and/or phrases that satisfy (often gratify) their users and/or readers but convey conflicting meaning. "Interdisciplinary research" is one such term. Few of its users have defined just what this research should really be and most readers have a wide variety of definitions. As a result of this confusion, "interdisciplinary" research has often floundered.

This note tries to clear this confusion by defining three types of interdisciplinary research: independent, supportive, and interactive. It then argues the virtues for each and suggests a continuum from one to the other.

Independent Interdisciplinary Research

At first glance, the words "independent" and "interdisciplinary" appear contradictory. How could anything be both "independent" and "inter . . ." anything?

Independent research is performed for its own scientific purpose by its own scientific specialists. Good independent research can lead to spectacular breakthroughs. In the rush to encourage interdisciplinary interaction, we must continue good independent research.

When independent research in separate disciplines shares something (anything) in common, it can gain interdisciplinary flavor. In the simplest case, this sharing may only be of resources. Such sharing inevitably brings independent researchers into contact with each other. Examples include a common building with shared seminar (or even social/lunch) rooms, a common platform like an airplane or tower, or common tools like computers or laboratory equipment. The research itself stays independent, but the surroundings can involve several disciplines.

In this age of strained and expensive resources, any sharing helps budgets. Things that help budgets help us all. Hence, the first benefit of this first class of interdisciplinary research is financial.

In order to have lasting impact, however, there should be intellectual, in addition to fiscal virtue. The dominant intellectual virtue of this first class of interdisciplinary research is that it introduces otherwise totally independent researchers to each other. Such contact often leads to the next kind of interdisciplinary research, supportive.

Supportive Interdisciplinary Research

Supportive interdisciplinary research is the most common kind today. Here, one discipline, the supporter, provides a service to another, the supported. Examples of supporting interdisciplinary research include the application of a technique or technology developed in one discipline to help another solve a long-standing problem. One example in ocean sciences is the application of new numerical techniques (from applied mathematics) to modeling. Another is the application of flow cytometry (from medical science) to observation of trace ocean constituents.

Air-sea interaction research is supportive when meteorologists take wind observations simply to provide upper-boundary conditions to an ocean-mixed-layer or wave model. Similarly, it is supportive when oceanographers observe sea-surface temperature simply to provide lower-boundary heat-flux sources to an atmospheric boundary-layer model. In the former case, winds observed by specialists trained in the nuances of wind observations (e.g., correct exposure) are likely to be more accurate and reliable than ones taken by people with more experience in the ocean. Similarly, sea-surface temperature observed by oceanographers who understand the difference between bucket and intake temperature versus temperature are more valuable than such observations taken by meteorologists.

In supportive interdisciplinary research, the benefit to the supported discipline is clear. That discipline gets, high-quality service performed by specialists who know their craft. What does the supporter discipline receive in return? One obvious benefit to the supporter discipline is financial compensation. If there is a depression in the supporter discipline's funding, this financial compensation can be vital, if only temporary.

It is rare, however, that a supporter discipline is satisfied in its supporting role, even during periods of funding stress. Hence, few researchers freely admit to this kind of interdisciplinary research. Usually supporter-discipline researchers seek *intellectual* as well as financial benefit from their support. When this intellectual benefit is substantial, the interdisciplinary research crosses into the third category, "interactive."

Interactive Interdisciplinary Research

Interactive interdisciplinary research is what the users and readers of the term "interdisciplinary" research should have in mind. Here, like independent interdisciplinary research, each discipline has an important issue of its own to study. Like both independent and supporting interdisciplinary research, each discipline has experts doing the job they know best how to do. The important additional feature in "interactive" interdisciplinary research is that progress in one discipline *relies* on progress in the other. Hence, each discipline has a vested intellectual interest in progress in the other. The total is clearly greater than the sum of the individual parts. This was the underlying goal of interdisciplinary research from the start.

Examples of pure interactive interdisciplinary research are difficult to find. Air-sea interaction is often cited as a classic example. In order to fully understand how the atmospheric (ocean) boundary layer evolves, one must understand how the ocean beneath (atmosphere above) evolves. Surely that sounds "interactive." But, do we really need to "understand" how the neighboring boundary layers evolve in order to understand our own? Or, do we simply have to "observe" the other and feed the correct forcing data? Will our understanding of one boundary layer really help our understanding of the other?

Surely, forecasting of one boundary layer will benefit from better forecasting of the other. But will better *understanding* of one benefit from better *understanding* the other. There are viable arguments both ways. I leave it to air-sea interaction researchers to answer that question and to convince their colleagues in the other discipline of their belief.

Air-sea interaction is not the only readily suggested example of interactive interdisciplinary research. Examples from the oceanographic community include biological-physical interaction, chemical-biological interaction, and chemical-physical interaction. Examples from the meteorological community include biological and chemical "feedbacks." Arguments can be made in all of these cases, that progress in one discipline depends, or at least *gains*, from progress in the other. However, the argument must be made and not simply considered as a given.

Technology Transfer

Cross technology transfer offers another example of interactive interdisciplinary research. At first glance, cross technology transfer suggests supportive, rather than interactive interdisciplinary research. It becomes interactive when the supported discipline needs more than state-of-the-art technology to advance. When technology improvements are needed by one discipline before that discipline can truly advance its own goals, cross technology transfer becomes interactive.

An example from numerical analysis makes the point of interactive interdisciplinary research. If the changing energy, latent heat release, in cloud physics processes requires the development of new numerical analysis techniques, then cloud physics research has a vested interest in numerical analysis research. If, the numerical analysis research, in turn, benefits from having a laboratory to experiment with new techniques, it is also gains from the interaction. When both disciplines gain, the research is interactive interdisciplinary research.

Summary

During times of constrained budgets and popular "buzzwords," it is appropriate to examine the true meaning, and virtue of "interdisciplinary" research. In order to survive and remain worthwhile, this type of research must have both financial and intellectual benefit. Otherwise, interdisciplinary research will suffer for the lack of first-line talent.

In this note, I define three types of interdisciplinary research, independent, supportive, and interactive. Independent interdisciplinary research allows specialists to retain the independence that traditionalists in the sciences often crave, while exposing them to the benefits of interaction. Supportive interdisciplinary research has the benefits of financial help to a discipline in need at a particular time. More important, however, it is usually the next step to true interaction.

In interactive interdisciplinary research, progress in one discipline both depends upon and gains from progress in the other. Although this is the best kind, and is what the term "interdisciplinary research" was originally supposed to mean, it is rarely achieved. All too often researchers and sponsors of work in the first two categories delude themselves into thinking they are in the third. This has been the single greatest obstacle to the wholesale embrace of interdisciplinary research.

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"Basin-Scale Ocean Monitoring with Acoustic Thermometers," Feature article by J.L. Spiesberger and K. Metzger (*Oceanography, 5:2,* p. 92–98).

Comments

By virtue of being listed as coauthor of the paper "Basin-Scale Ocean Monitoring With Acoustic Thermometers" and the use of the word "we" in the second paragraph of the section labeled "Future Possibilities," the impression has unintentionally been created that I am a member of the Ocean-Climate Acoustic Thermometry (OCAT) group. OCAT is an effort of John Spiesberger's in which I am not participating.

I feel that the paper might have made it more clear that the development of the "acoustic thermometer" was an evolutionary extension of existing techniques rather than the creation of a totally new approach. Other workers have been making similar measurements at shorter ranges. Worcester *et al.* (1991) and Spindel and Worcester (1990) review the development, listing 15 major tomographic experiments, including those discussed in the paper, with the first in 1978.

Spindel, R.C. and P.F. Worcester, "Ocean acoustic tomography programs: Accomplishments and plans," Proc. OCEANS' 90, Washington, D.C., Sept. 24–26, pages 1–10, 1990.

Worcester, P.F., B.D. Cornuelle, and R.C. Spindel, "A review of ocean acoustic tomography: 1987–1990," Reviews of Geophysics, Supplement, pages 557–570, April 1991. U.S. National Report to International Union of Geodesy and Geophysics 1987–1990.

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"Graduate Education in Physical Oceanography," Review & Comment article by Joseph Pedlosky (*Oceanography 5:2,* p. 117–120).

Comments

I am writing this not to dispute what the author has said but rather to offer a few particulars that might serve to keep alive the debate he has started. To decide on the shape of graduate programs of the future, we need to ask about the directions in which physical oceanography is evolving. According to the author, physical oceanography has become "the study of the physics of the oceans, with a special focus on the dynamics of oceanic currents and waves." I suggest that we should help physical oceanography to evolve toward being a form of ocean physics with a full range of topics and with a strengthened emphasis on problem solving.

In particular, the physical oceanography of the future should place topics such as underwater acoustics and marine optics on an equal footing with what might now be called ocean dynamics. Perhaps all Ph.D. students in physical oceanography should be required to complete at least one graduate-level course in underwater acoustics and another in marine optics. But how can we make room for courses like this in those programs that previously did not include them? One way would be to move some of the advanced undergraduate material now taught in graduate school to where it belongs—in the undergraduate departments of colleges and universities. This might require that we do some work as advocates to get physics departments (not doing so now) to offer advanced undergraduate courses in subjects such as acoustics and fluid mechanics (and to avoid skipping the corresponding chapters in general physics courses). If this is done, the results could have fringe benefits: for example, it might create positions for more Ph.D.s in physical oceanography to move into physics departments to teach these undergraduate subjects. And how would the smaller graduate programs that do not now have suitably qualified professors offer graduate courses in topics such as underwater sound and marine optics?—by using the consortium ideas suggested by the author.

As for a strengthened emphasis on problem solving, a good place to start would be to make sure that all new physical-oceanography textbooks contain problem sets with answers (for a full range of topics). That the only such books with any hope of introducing the dynamical aspects of physical oceanography now have no problems is amazing. The essence of physics is problem solving, and we should expose the students to this idea as early as possible. To facilitate problem solving (and relieve some of the struggling over the mathematical aspects referred to by the author), future graduate physical-oceanography programs should phase shift various mathematics courses into earlier positions. And physical-oceanography teachers should perhaps become less casual about letting students take mathematics courses concurrently with the physics that depends on them.

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Comments

Having just finished a review of education in oceanography (Leipper, a talk, *Oceanography Undergraduate Programs, Some Essential Functions,* April, 1992), and having been associated with graduate programs in oceanography at three institutions (26 years as chairman) since 1943, I was particularly interested in the thoughtful discussion of graduate programs in physical oceanography by Pedlosky.

Pedlosky is concerned, on the one hand, "whether the traditional prescription of breadth, as manifested in *The Oceans,* is the correct one," or, on the other hand, as at a few universities, "whether we are producing a breed of overspecialized professionals." (Quotations with no indicated source are from Pedlosky.)

This is the same question that faced scientists in the late 1940s when an article was authored by two oceanographers representing, respectively, Scripps and Woods Hole together with their Deans at the University of California and at Massachusetts Institute of Technology. (Knudsen, Redfield, Revelle, and Schrock, Education and Training of Oceanographers, *Science,* 23 June 1950.) They gave specific answers.

The wisdom of these authors has guided the curricular development at many institutions. It is still remarkably useful. The article defines oceanography and outlines disciplinary guidelines for curricula to the masters level. It gives a quite different view of curricula in physical oceanography from that which material in the book *The Oceans* implied to Pedlosky. The Knudsen program for physical oceanography prescribes and encourages considerable depth in the physical sciences. In the 1950s, we at Texas A&M added a specialization in meteorological oceanography. My 1992 talk presented a straw man for a bachelor's program in the physical as well as in the other aspects of oceanography modified from the Knudsen program.

The Knudsen article was based on experience gained in the curricular offerings which, after other considerations such as the nonlecture approach, began at Scripps in 1946. This was "a formal program of professional education" at that early time. Those of us who were studying physical oceanography in this first class were nearly all meteorologists, and some had engineering backgrounds. Also, for example, I had a masters in math. The physical oceanography was taught by "teachers who were themselves trained as physical oceanographers" (e.g., by Sverdrup, Revelle and Munk). Because this 1946 and subsequent curricula match what Pedlosky says "is now common," there seems to have been no "radical transformation" since that time "in the manner in which new recruits to the field are educated."

In practice, the formal "broadening" in the oceanography curricula, with which I am familiar, consists of about nine semester hours at most. In most institutions there is also interesting and useful exposure to other specialities such as in seminars and in team work on research cruises.

The "specialization" in the student's program comes from his/her particular undergraduate background and from graduate courses and research in the extensive remainder of his/her graduate program. In my experience, the interdisciplinary broadening and the resultant first-hand knowledge about the other disciplines lead to a stimulation of research in physical oceanography. They certainly are not "paralyzing to creative research." However, it is true that there are some problems that do not need this stimulation. These are problems in "oceanic physics," as Pedlosky called them, rather than in oceanography.

If there is concern that the "shrinking number of acceptable applicants in the pool has led to a kind of frenzied competition between schools," the conclusion of the Joint Oceanographic Institutions (JOI) Deans (Nowell and Hollister, EOS, 6 September 1988) is reassuring: "From the studies of all applicants' names to the JOI schools, we conclude that the ten schools do not compete against one another, but rather against schools outside oceanography."

The establishment of additional approved undergraduate degree programs in oceanography (Leipper, 1992) would ameliorate many of the problems mentioned by Pedlosky. These programs could guide students into the most appropriate undergraduate courses in physics, applied mathematics, meteorology, engineering, descriptive oceanography, field work, and research methodology. They would increase the number of acceptable students for graduate programs, would reduce the necessity for teaching preparatory courses in graduate school, and would give students a better start in graduate programs. Following the Knudsen definitions and guidelines would also be helpful.

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Reply to Comments

I am delighted that my remarks about graduate education in Physical Oceanography have led to further discussion on this most important issue for our field.

I agree entirely with Dr. Korgen that our subject could embrace a "full range of topics and with a strengthened emphasis on problem solving." It is true however that Physical Oceanography can best be described as that thing which Physical Oceanographers do. On the whole, this is the study of oceanographic currents and lower-frequency motions than acoustics. In my own institution acoustics seems happily to have found a home in our Applied Physics and Ocean Engineering Department, probably because of its tie-in with acoustic measurement strategies in the oceans. Historically of course, acoustics found a home in many physics departments, but then again so did geophysics and even oceanography, and it might some day do so again.

In the meantime, the question "how we can make room for courses like this" lies at the heart of the debate I wanted to start. Making room is making choices. These are choices based on opinions about where the field has been and where it is going. The choices are choices based on estimates of the intellectual value of past work and predictions of future needs. Something will always be left out, there will always be gaps and each faculty has the responsibility to craft an academic program that that faculty thinks is the most intellectually exciting, durable, and feasible. Adding more courses to existing programs is in many places a practical impossibility, and a major restructuring of teaching, as I suggest in the article, may be the healthiest alternative available to us. I do feel that adding fluid-mechanics courses to undergraduate physics curricula would be good for everyone, but I don't think it will answer the need to restructure our graduate programs.

I found Dr. Liepper's discussion of the history of the educational program at Scripps to be fascinating. I think it is fair to say that we still have different notions on what range of possibilities exists in defining "breadth." A good deal of modern development in fluid mechanics, mathematics, and physics is not being taught to our students and would be less accessible if the curriculum required courses in other branches in oceanography. I want to emphasize that I fully encourage those students who want to know more about parallel branches of oceanography to be able to study them if their personal vision of breadth in education and research tends in that direction. I would not insist on any particular such direction because I can think of many legitimate alternatives.

What I believe contributes to paralyzing many students about to begin their research is the fear that they must know everything *before* they start. The sooner they get underway with a serious problem, the sooner they will begin to appreciate what they need to know and the depth and commitment required of the knowledge. This doesn't make it any easier to construct an academic program. I don't think this means just throwing the student into the water and hoping he or she can swim and do research at the same time. Some preparation and guidance, some real teaching, is necessary. As teachers, this is how we earn our wage. What we as teachers have to struggle with is what form that teaching should take as our field matures.

Of one thing I am pretty sure: I do not believe we should encourage undergraduate programs in Physical Oceanography. I think students in such programs are intellectually short-changed in college and do not receive the robust education that is needed to form a foundation for graduate study. I do agree that more classical physics in the physics departments' curricula would be beneficial both for physics teaching and for the future of our field.

One final, perhaps cranky remark might be allowed. I am familiar with the Nowell and Hollister report and its conclusion that we do not compete against each other for students. This may be true on the numbers. Any of us actually involved in the admission process knows that our success in any particular year is more likely to be measured on whether we have been able to attract what we identify to be "star" material. As a consequence we, and several of our sister institutions, now have programs to fly successful applicants around the country on whirlwind visits to several programs where they are wined, dined, and entertained as they may never be again in their entire careers, often on the basis of the slender evidence in an admission file to which we sometimes return years later with shaking heads to try to understand the motive for such enthusiasm.

All the ideas expressed by Drs. Leipper and Korgen have been helpful in stimulating a review of our educational philosophy; a review which in my opinion is very much needed.

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"Let Roger Revelle Speak for Himself," News & Information article by W.H. Munk and E. A. Frieman (*Oceanography 5:2,* p. 125).

Comments

The note "Let Roger Revelle Speak for Himself" by Munk and Frieman makes the incorrect implication that Roger Revelle's coauthorship of the April 1991 article in the *Cosmos Journal* by Singer, Revelle, and Starr entitled "What To Do About Greenhouse Warming: Look Before you Leap" was merely a casual act by Revelle. This is totally false. Revelle participated in both the context and galley proof corrections in preparation of the manuscript, and the paper does reflect his views.

The 1990 AAAS speech of Revelle, reprinted in *Oceanography* on the following page, presents views that were reiterated in the 1991 *Cosmos* article. The three authors were concerned that the constantly shifting scientific base for predictions about climate warming was inadequate for prescribing drastic public actions. We agree with Munk that Revelle believed in "informed activism," but he also was cautious about the quality of information on such an important issue as greenhouse warming.

The timing of this complaint by Munk and Frieman about the *Cosmos* paper is most curious. The paper appeared in April 1991. Revelle died in July and was actively interested in these matters to the very end as mentioned in the Munk/Frieman letter. No one, including Revelle, raised any doubts about the paper. A year later, after the 1992 nomination of Senator Gore, a journalist chose to use the *Cosmos* paper to criticize Gore's views as expressed in his book. Since that time we have been harassed on the question of Revelle's authorship. We consider this a disgraceful attempt to politicize and rewrite a scientific publication. Further, it is an insult to the memory of Roger Revelle to imply that he didn't know what he was doing. We suggest that a reading of the *Cosmos* article would quickly show the consistency of Revelle's position.

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Editors's Note: The introduction submitted by Munk and Frieman (and the article by Revelle) was accepted for publication with the intention of stimulating discussion within the oceanographic community about an important scientific and environmental subject.

The article by Singer, Revelle and Starr was published in *Cosmos, 1,* 28.