Teaching and Communicating Physics

Janez Strnad

Faculty of Mathematics and Physics, University of Ljubljana, Slovenia
janez.strnad@fmf.uni-lj.si

Is communicating physics to the public a continuation of teaching physics by other means? Answers are sought on the basis of personal experience.

Introduction

In a guideline for lecturers, younger ones were advised to stick to an impersonal style whereas older ones were encouraged to refer occasionally to experience.

Forty odd years ago I began to give the introductory physics course for physics majors at our Department. Textbooks for freshmen followed in due time and textbooks for sophomores somewhat later. Observing the interest of freshmen in parts of modern physics, which the introductory course did not cover, I wrote booklets on relativity and quantum physics for interested high school students and freshmen. Later on I wrote also physics textbooks for high school. I contributed articles to popular scientific journals, prepared broadcasts for the radio, and wrote popular books. Now I am pursuing this full-time. Apparently, I underwent a smooth transition from teaching to communicating.[14]

The experiences, which I will try to share with you, may be of some importance for communicating physics as well as for teaching physics. Nevertheless, the majority of my ideas can not be tested in the sense characteristic for physics. They are intended to stimulate reflection and discussion and may cause opposition.

Three activities

Let us envisage three main activities of physicists:

- research,
- teaching,[15]
- communicating to the public.

Correspondingly, the group of physicists may be considered as being composed of three subgroups: researchers, teachers, and communicators. The subgroups are overlapping, there are few full time communicators.

- Physics is the basic natural science and is relying on the scientific method. An idea is tested by comparison directly with observation or measurement. In case of disagreement

[14] Lecturing physics to nonscience students, ``physics for poets" or ``physics as liberal art", may be considered as an intermediate step.
[15] ``Teaching" is used instead of the somewhat broader ``education" and ``teachers" and ``students" refer to all levels.

the idea is abandoned or modified. ``A theory can never be proven right.'' [1] In the community of physicists a consensus is reached or at least a well defined majority view. Research in physics is universal.

- Physics teaching on the one hand is tightly bound to physics. The American Association for the Advancement of Science AAAS requires that ``science should be taught as science is practiced at its best.'' [2] But reliable standards are lacking [3]. ``Change in physics teaching is long in development and poorly communicated.'' [4] Development in physics teaching is not cumulative or additive [5], it is partially circular. Experiments in physics teaching suffer from deficiencies typical for experiments with humans [6]. The participation in an educational experiment may influence the performance of teachers and students [7]. So in issues typical for teaching, the scientific method cannot be applied directly. On the other hand, in an administrative sense, with respect to journals, the possibility to acquire academic titles, and jobs, teaching physics is an independent activity. Educational systems in various countries differ considerably. Thus, teaching is not universal. Seminars like this, however, give the teaching of physics a universal trait.

- Communicating physics to the public is more diversified and less standardized than physics teaching [8].[16] As in teaching, in issues typical for communicating, the scientific method cannot be applied directly. In an administrative way, with respect to journals, academic titles, and jobs, it may in future acquire an independent status. The first journals, e.g. *Public Understanding of Science*, and departments, e.g. at the Imperial College London, have been established already. Conditions for communicating physics to the public vary from country to country. Thus, communicating physics is not universal. Translations of a few popular journals and some best-selling popular books give it a universal trait.

``Qualitative'' and ``quantitative''

In trying to analyze teaching and communicating physics on a common footing the terms ``qualitative'' and ``quantitative'' are introduced. ``Quantitative'' involves numbers, counting or measuring, the use of symbols and equations, and ``qualitative'' expressing something with words only. [9][17] This is a simple two-group model for a continuous spectrum, a somewhat arbitrary one as other parameters might be taken into account: readability, human interest, density of scientific terms or information density [10].

We study qualitative and quantitative ingredients separately in three activities in teaching physics, which we call for short:

- lecturing,
- experimenting,
- problem solving.

- In lecturing the teacher is addressing all students or is leading a discussion with them. In a basically similar situation is the textbook author. The initial lecturing before quantities

[16] A variety of synonyms or approximate synonyms exists: popularization of physics, physics outreach, promotion of physics, public understanding of physics, physics literacy, physics awareness.
[17] Thus, we give the terms a somewhat narrower meaning than usually.

and laws are introduced, is qualitative whereas lecturing thereafter may be either qualitative or quantitative.

Qualitative lecturing is important at the beginning of a new chapter to arise the curiosity of students and to persuade them of the significance of the discussion to follow. It is usually followed by quantitative lecturing introducing quantities. Finally, after the law is obtained, the complicated topics may be considered qualitatively, giving vistas, and describing the content of lectures to follow.

- Experiments are of primary importance in physics research. In physics teaching they have a different role. Usually simple and inexpensive apparatus is used giving results of limited accuracy. Demonstration experiments directly accompany the lectures and student experiments are performed by students individually or in small groups usually in the laboratory.

  Qualitative experiments showing one outcome in unchanged conditions are rare. More often something is changed and the increase or decrease of another thing is observed. Let us call experiments of this kind *semi quantitative*. Such experiments are very important as performing them, students can learn to ``manipulate the environment''. ``Children can measure and compare [semi] quantitatively long before they can understand the simplifying and sophisticated concepts that we have developed.'' [11] Such are also the *hands-on experiments* in museums and science centres. These experiments can be done before quantities and laws are known [12].

  Quantities are measured in *quantitative experiments*. Such are mainly experiments done by students in the laboratory, often measuring the dependence of a quantity on another, and writing a protocol.

- Problem solving is a quantitative activity. After the respective quantities have been introduced and the law was arrived at, the teacher usually solves some problems to show the quantities and the law at work. Thereafter the students do problems as homework. ``The homework problems are undoubtedly the key to the system. [...] Each problem creates what is technically known as Need To Know.'' [13]

  An important goal is to connect problem solving with semi quantitative-type discussions of the features of their solutions. Has the result the right order of magnitude? Does the obtained dependence make sense? This is a crucial link between quantitative and qualitative, or conceptual, reasoning. In this case semi quantitative reasoning is following the quantitative one, not preceding it. ``In solving a physics problem, getting on to an algebraic expression which is `the answer' is *only* half the fun. The other half is examining the expression to find whether it has the characteristics that you expect.'' [14] Some call this method ``reading the equations''. [15] Qualitative questions, which are considered to be very important, also follow quantitative and semi quantitative considerations. *Conceptual physics* stresses the semi quantitative discussion after the laws have been established.

  Lecturing, experimenting, and problem solving were considered as mutually independent and analyzed separately but, in fact, they are often used in combination.

Communicating physics

Various reasons are given why communicating physics to the public is important. Let as quote some of them.

An understanding of physics is necessary for a full participation in society.

Physics is an important part of our future. Society becomes intertwined with physics.

In a society that is functioning effectively, an understanding of physics and its methods is a basic requirement for all.

Without understanding of physics and its methods, the public will not be equipped to make rational choices concerning the risks and benefits of technologies.

Popularizing should transmit to nonphysicists the inherent excitement and underlying goals of the discipline.

The laymen may appreciate that physics is a rational result of cognitive processes and not magic.

Modern physics is the most positive achievement arrived at in the last century.

Physics awareness should curb the declining numbers of physics students.

Physics awareness is necessary to keep back the flood of pseudoscience.

In the above statements ``physics" is sometimes replaced by ``science" and/or ``technology".

Physicists take part in this activity for various reasons, often because they simply like it. The academic bonus is modest, and the earnings small, except for best-selling books.

Individual scientists and institutions attempt through communicating to the public to promote their work: ``Popularizing physics means disseminating research results to nonexpert audience. That dissemination is a natural extension of physicists' efforts in writing journal articles and presenting conference talks." [16]. Thus, this kind of communicating physics to the public is connected directly with research.

Data on the participation of physicists in communicating physics are scarce. Of practicing scientists, members of the U.S. scientific society Sigma Xi, ``74 % did not have time for public outreach, and 41 % believed their involvement makes no difference". [16]

Sources of science and technology information in the U.S. in 2001. (The left hand side corresponds mainly to qualitative and the right hand side to quantitative reasoning.)

Science and technology news		*Specific scientific issue*	
Television	44 %	Internet	44 %
Magazine	16	Books	24
Newspaper	16	Magazine	~8

Internet	~9	Other	~8
Other	~5	Television	~6
Radio	~3	Don't know	~5
Family, friend, colleague	~3	Newspaper	~4
Books	~2	Family, friend, colleague	~1
Don't know	~2		

Preliminary data for over ten thousand members of the French Centre National des Researches Scientifique CNRS from July 2003 to June 2004 show that 76 % did not get involved in physics outreach. 21 % have carried out some activity, on the average once or twice a year, and 3 % on the average 6 activities. The most active 10 % contributed 70 % and the top 5 % contributed 50 %. The activities increase moderately with age from 0,45 of an activity per year for those aged 31-35 to 0,7 for those aged 56-60. The proportion of scientists carrying out activities varies from 17 % for general physics, chemistry, and biology to 30 % for astrophysics and 41 % for social sciences. Speaking on conferences on popular science is the most common activity (25 %), followed by writing newspaper articles (23 %) or giving radio or television presentations (17 %). Social scientists appear on radio or television much more frequently [17].

This data, although sketchy, hint that the community of physicists would have to put much more efforts to communicating to the public if the suggestion [18] should be fulfilled: ``[...] that the physics community undertakes to devote 5% of its aggregated effort to the nurture of Public Understanding of Science. To their traditional responsibilities for research, teaching, and service, university departments should add an obligation, not unlike the *pro bono* work of doctors and lawyers, to perform this task. The work might fall on one physicists in 20, full time, or it might be shared among many."

In teaching, physics is presented systematically and the knowledge continuously assessed. On the contrary, it is typical for communicating physics that the consumer chooses freely when and how to participate, often in an unsystematic way. However, this bears witness of special interest on the side of the consumer.

Physics is communicated to the public in a qualitative way, mostly by qualitative lecturing without explicitly referring to the laws of physics. Thus, the main distinction between teaching and communicating is that in the former quantitative reasoning is used but not in the latter, at most semi quantitative ingredients being admitted. So the means of communicating physics are much more limited than of teaching. Besides talks, also on radio, and publications remain semi quantitative hands-on experiments in museums and science centres. The presentation is less restricted on television where phenomena and experiments can be shown directly. So teaching and learning enable one to use physics, whereas communicating and reflecting on physics do not. As R. Hazen and J. Trefil in *Science Matters* clearly state: ``[...] scientific literacy constitutes the knowledge you need to understand public issues. It is a mix of facts, vocabulary, concepts, history, and philosophy. It is not the specialized stuff of the experts [...]. The fact of matter is that doing science is clearly distinct from using science. Scientific literacy concerns only the latter." [2]

Limitations

One should not avoid to mention the limitations of communicating physics to the public. There are indications that pupils at an early age, e.g. between 10 and 14, by a personal decision accept science or reject it. This phenomenon has not received such attention as ``math anxiety''. ``What appears to link students of very diverse mathematical `ability' is a collection of what might be called ideological beliefs or prejudices about the subject. Students' early experiences with mathematics typically give them false impressions not only of the nature of the subject, but also, and more perniciously, of the kind of skills required to master it. [...] The problem [...is] not residing in a particular pedagogy, not even in `poor teaching', but rather in students' self-perceptions and in a belief system that rests on the presumptions that either one is mathematical or is not. [...] Among physics students or potential physics students there appear to be two non-overlapping populations: those whose anxiety is a result of exposure to physics courses and those whose anxiety, or better stated, apprehension, keeps them from trying physics even once. In the case of math, the anxiety is usually the result of exposure to math courses, whether the student is successful or not. [...] Not so, it appears in physics. [...] Hence, either the preselection process in physics is more effective in weeding out the timorous and the underprepared or the anxiety-by-doing in physics is somewhat less of a problem.'' [19]

Paraphrasing a statement for students: ``there is another factor, which is overlooked: *Perhaps some people just aren't interested in science, no matter what we do to capture their interest*.'' [20] An extreme case was the poet Sylvia Plath who wrote: ``The day I went into physics class it was death.'' [15] This phenomenon is probably the root of Ch. P. Snow's two cultures. Thus, an appreciable part of the population is almost inaccessible for communication of physics and only the natural-sciences-friendly part can be informed. This shows how important it is to bring natural science in general and physics in particular to the young. Of course, the picture of two distinct groups is oversimplified, the other extreme would be to consider a continuous spectrum.

Further, there is a somewhat related weakness. ``Physics and the scientific worldview often elicit hostility and anxiety because we have become a society where `bad' news sell papers.'' [21] ``Globally, it [indifference towards physics] characterizes the attitude of virtually 100 % of the population. The trouble is that although science affects the life of every human being, it does so indirectly. [...] In order to reach the public, we must engage its feelings and passions by exposing our own. We must give something of ourselves, even if it is only an anecdote of our youth, a private observation, an admission of what moves us. Contrary to everything we have been taught about scientific discourse, we must learn to express our feelings if we are to communicate more effectively with the public.'' [18]

Not many emotions can be shown in considering quarks and quasars, which are far away from human problems. But this may be done in discussing our environment: the limited resources on earth, energy shortage, danger of overpopulation, global warming, the ozone hole etc. As physics and other natural sciences are often accused for the deterioration of the environment, here is the opportunity to emphasize that physics is in fact environment-friendly. Its measuring devices monitor changes in the environment and within its framework new environment-friendly processes and apparatus are developed.

In communicating to the public, physics should not be presented in an unrealistic fashion, with physicists ``as infallible creatures on the path to certain truth''. ``Portraying science in this unrealistic way just creates unrealistic expectations that fuel `antiscientific' reactions when those expectations are not met''. Bruce Lewenstein, editor of *Public Understanding of Science*, asserts that the public should know the scientific method, but not the idealized one of hypotheses and testing, ``but rather the messiness of how we come to have reliable knowledge of the natural world''. ``The public would then understand why scientists cannot provide `the' answer to various questions." According to John Durant, professor in the public understanding of science at the Imperial College London ``scientists need to be candid about what is and isn't known. [...] They should remember that scientific knowledge is not always certain and complete." [22] On the other hand one should neither overstress the boundaries of our knowledge. Before somebody can understand the ``messiness" and the boundaries of our knowledge she or he should have an impression of what the body of knowledge is.

Experiences

I was contributing in Slovenian to a newspaper, radio[18], and popular journals, wrote books, and gave lectures for nonphysicists. I have some, not a good one, experience with television. To illustrate my activity the titles of the most recent five texts are quoted.

- *Delo* (Work), science supplement of a newspaper:
    - Einstein's first work in the miraculous year. On the emission and absorption of light, 2005,
    - Einstein's Ph.D. Thesis. His mostly cited work, 2005,
    - Einstein's third work in the miraculous year. Brown's motion, 2005,
    - A neutron generator with a pyroelectric crystal. ``Table top fusion", 2005,
    - Einstein's fourth work in the miraculous year. The special theory of relativity, 2005.

The texts are qualitative.

- *Radio Slovenija* (Slovenian radio):

I have presented stories of famous physicists. In the first part of a story the times and the life of the scientist are described and in the second part her or his contributions to physics. From 1995 to now these stories were published in five volumes. Therewith I have anticipated the recommendation of the European Physical Society: ``Tell stories about the life and discoveries of scientists. Stories can be easily followed and into the text of a story even some technical details can be incorporated without loosing the interest of a wide audience."

- *Proteus*, a popular scientific journal:
    - Polarized light, 2004,
    - The Nobel physics prize for 2004, 2004,
    - How to teach science, 2004,
    - On physics, science, and teaching, 2005,
    - The International Physics Year 2005. 2005.

The texts are qualitative, only exceptionally an equation may appear as a label.

- *Presek* (Intersection), a journal for young mathematicians, physicists, and computer scientists:
    - On friction (in three parts), 2004,
    - The 125th anniversary of Einstein's birth, 2004,
    - The ship and the bubble, 2004,
    - The speed of light is the limit, 2004,
    - The mass of energy revisited, 2004.

[18] Radio is a powerful agent against quantitative reasoning.

The texts usually consist of two parts, the first being qualitative and the second one, which the reader may drop, quantitative.

- *Spika*, a popular astronomical journal:
  - Light in the universe, 2001,
  - The new standard model of the universe, 2002,
  - Light in the ``new standard model" of the universe, 2004,
  - J. Vega and planetary masses, 2004,
  - Astronomy and optics, 2004.

In some texts the model of the universe was considered quantitatively.

- *Fizika v šoli* (Physics in School), a journal for physics teachers:
  - Galileo (and GPS) and the teaching of physics, 2003,
  - Ten men towards the law of refraction, 2003,
  - On Newton's law of motion, with G. Planinšič, 2003,
  - Aristotle's law of free fall, 2004,
  - Hundred years of physics, 2004.

The texts contain equations and derivations.

- *Obzornik za matematiko in fiziko* (Review of Mathematics and Physics), a journal of the Society of Mathematicians, Physicists, and Astronomers of Slovenia:
  - A new Millikan's experiment, 2004,
  - On Einstein's first paper, 2004,
  - The first estimates of molecular radii, 2005,
  - Rewarded asymptotic freedom, 2005,
  - The way to the special theory, 2005.

The texts are quantitative. In the list of articles a step-wise transition from qualitative to quantitative reasoning can be followed.

- *Books, textbooks excluded*:
  - The World of Measurements, 2001,
  - A Hundred Years of Physiscs/ From 1900 to 2000, 2001,
  - Physicists, Fourth volume, 2004,
  - Einstein. His Life, His Work (two volumes), 2005.
  - Physicists, Fifth volume, 2005.

The books are qualitative with the exception of *The World od Measurements* and *Einstein. His Work*.

In working with newspapers and radio the cooperation with editors and journalists was important[19] Thereby occasionally some tension arose which, from a sociologist's point of view, is natural. Physicists on the one hand and journalists and editors on the other have different professional standards. There was not much feedback and requests for texts, the most interest was shown for nuclear weapons and rockets. I got occasionally appreciative remarks, mostly from fellow physicists.

[19] The role of science journalists, which is very important in communicating physics to the public, would deserve a separate discussion.

A consensus exists that at present communicating physics to the public in our society is becoming a necessity. Thereby we should not wait that communicating to the public ``should qualify for the customary awards of the academy including merit raises, promotions, and honors." [18] This may prove to be a long-term project as communicating to the public is less standardized and more diversified than teaching. It is not easy to judge the performance even in teaching and the existing hierarchy in university departments is based mostly upon the performance in research. So at present a personal preference towards communicating physics to the public and the decision to do it is of primary importance. To those of you who up to now have not communicating physics to the public but shall do it in future I wish to have as much fun as I had.

References

[1] Feynman R P, 1965, The Character of Physical Law, (London; Cox and Wyman)

[2] Wehrbein W M, 199,6 What shall we teach nonscience students about science?, Am. J. Phys. 64, 363

[3] Reif F, 1996, Standards and measurements in physics -- Why not in physics education, Am. J. Phys. 64, 687

[4] Wilson J M, 1988, Changing the introductory physics sequence to prepare the physics student of the 1990s, Proceedings of the Conference on Computers in Physics Instruction, J Risley (ed), (Reading, Mass.; Addison-Wesley)

[5] French A P, 1999, Learning from the past; looking to the future, Am. J. Phys. 57, 587

[6] Swartz C, 1994, Research has shown, Phys. Teach. 32, 6

[7] Romer R H, 1989, Spin-½ quantum mechanics? -Not in my introductory course, Am. J. Phys. 57, 491

[8] Simmons E H, 1995, How to popularize physics, Phys. Today 58, 42 No 1

[9] Strnad J, 1998, The role of qualitative and quantitative reasoning in physics education Conference New Tendencies in Physics Education, Puebla, Mexico 1998 (unpublished)

[10] Strnad J, 1985, On communicating physics to the public, International conference on physics education (Duisburg) p 382

[11] Swartz C, 1991, A quantitative misconception, Phys. Teach. 29, 486

[12] Gregory R, 1990, Hands-on science: its contribution to physics and education, Phys. Educ. 12, 233

[13] Swartz C, 1993, Book learning, Phys. Teach. 31, 134

[14] Styer D F, 1998, Getting there is half the fun, Am. J. Phys. 66, 105

[15] Romer R H, 1993, Reading the equations and confronting the phenomena -- The delights and dilemmas of physics teaching, Am. J. Phys. 61, 128

[16] Augenbraun E, 2005, Weapon of mass attraction, Nature 433, 357

[17] Jensen P, 2005, Who's helping to bring science to the people, Nature 434, 956

[18] von Baeyer H C, 1998, Science under siege, Am. J. Phys. 66, 943

[19] Tobias S, 1985, Math anxiety and physics: Some thoughts on learning "difficult" subjects, Phys. Today 38, 61 No 6

[20] Ciparick J D, 1992, Culture, values and the wish to learn science, Phys. Today, 45, 108 No 6

[21] Patel K, 1990, Communicating physics to the public, Phys. Today 43, 23 No 11

[22] Durrani M, 1999, Physicists must learn to love the public, Phys. World 12, 71 No 12