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CONCEPTUAL EVOLUTION IN PHYSICS
A CASE STUDY OF THE NEW DIDACTIC SYSTEM: PHYSICS IN 700 EXPERIMENTS

by

Michael J. Higatsberger
Professor of Physics
University of Vienna
Vienna, AUSTRIA

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Michael J. Higatsberger
University of Vienna, Austria

I. Introduction

Presently there is no European country without physics teaching at high school level. The ancient Greek schooling system based its natural philosophy teaching on elements of physics. In central Europe an organized physics teaching program was generally introduced around the middle of the 16th century. At that time the inductive method in physics was used to find and evaluate the principle physics laws. It took about another century until regular physics courses were taught in most of the European countries.

The need for physics teaching was closely related to the industrial growth and prosperity at that time. Nevertheless it was not until the middle of the 19th century which can be claimed to be the real starting point of general physics teaching in all European countries. Even then there were a few countries which started their regular physics teaching system only at the end of the 19th century. If one asks today the question what are the reasons for teaching physics at high school level, the answers can be summarized as follows: Physics is a necessary background for well-educated people, physics is part of the cultural development, it is needed to improve the economy and thus is an important service function to society. The famous Robert Bunsen, professor of chemistry at the University of Heidelberg about 130 years ago, put it this way: "Ein Chemiker, der kein Physiker ist, ist gar nichts."

II. European Trends in Physics Education

In 1981 the European Physical Society finished an empirical investigation of the Advisory Committee on Physics Education of EPS entitled "Physics education in secondary schools - European trends". This report was presented at the 5th General Conference of EPS held in Istanbul in 1981 by G. Born and R. Wickihalter. The report was based on questionnaires sent to 27 European countries covering the following topics: general organization of secondary school education; place of physics in secondary education; the physics curriculum; the physics teachers; the pupils; and the general situation.

The general results were that in central Europe two types of secondary school education systems seem to exist: the parallel form and the comprehensive form. The leading countries in the parallel form system are Austria, Belgium, Federal Republic of Germany, France, Great Britain, Greece, Luxembourg, Ireland, Israel, the Netherlands, Portugal and Switzerland, while the rest of the countries like Finland, Italy, Spain, the Scandinavian countries, the Soviet Union, Turkey and the Eastern Bloc countries use the comprehensive form.

In the parallel form the students are divided according to their intellectual abilities to at least two different school types (humanistic and realistic forms), while in the comprehensive form all students above a certain age are educated at a combined humanistic and realistic level. The study revealed great national variations on the minimum need for physics teaching. The EPS recommended that physics should be taught to all students during the whole school education for at least two lessons per week. These recommendations have only been implemented by a few countries so far. On the other hand in the majority of countries physics is compulsory for at least three years. Many countries offer additional optional courses. In total physics is taught during general secondary education for a minimum of two hundred hours to a maximum of seven hundred hours. These great fluctuations seem to be closely connected with the qualification of physics teachers and their didactic abilities.

Pedagogical and didactic training for physics teachers at college or university level vary from about five percent in Greece and the Netherlands to about thirty percent in Denmark, the German Democratic Republic and Hungary. The Advisory Committee on Physics Education of the EPS concluded from the evaluation of the questionnaires that in many European countries physics teachers are not necessarily specialist teachers and that senior level physics teachers receive on the average much less pedagogical and didactic training than junior level science teachers. It was also found that only in a few countries well-organized systems exist to continue some form of further physics education for practising teachers.

As major problems were pointed out the limitation in time for physics teaching at secondary level, the lack of experimental and laboratory equipment and that many students are not able to apply physics in practical cases. To improve the situation it was suggested that physics should be embedded in a more general science curriculum and thus being part of an integrated science which lead in some countries to a polytechnic education. To counteract present-day resistance and rejection by some groups of the society against technology as such, popularization of physics was recommended and a planned research into physics teaching.

Topics of physics education on national and international levels were and are under review all over the world. For the American Association of Physics Teachers (AAPT) the subject has top priority as it has for the International Union for Pure and Applied Physics (IUPAP) or for UNESCO. But also in a small country like Austria physics education and training is scrutinized permanently. The boundary conditions are here quite different from any other part of the world. In Austria unity exists for physics research and physics teaching. One basic law of the Austrian Constitution states: "Teaching and Research are free." Even the General Act on University Studies of 1966 restates that "the unity of research and teaching" remains a guiding principle for the organization of university studies, because "to deprive universities of their research activities and potentialities would be to reduce them to higher specialized schools without any intellectual creativity and power. The major stimulus for active teaching is the research activity of the teacher." Physics teachers at high-schools are university graduates,their prior experience is ~~fed~~ into their way of teaching. The research they have carried out at university level also guarantees that teaching takes account of up-to-date new scientific developments. Apparently up to now the Austrian physics education system does not suffer major draw backs since almost forty percent of all physicists who graduated in the past twenty years from Austrian universities found jobs in highly technical and industrialized countries in the western hemisphere. From the sixty percent of physics graduates who remained in Austria roughly one third became high-school physics teachers. It is a long-time practice to organize throughout the year seminars and lectures to refresh the physics knowledge of the active teachers. Every year the Austrian Association for Teachers of Physics and Chemistry arranges a postgraduate training week at the University of Vienna. The program scope includes lectures on the fore-front of international developments, practical performances of lessons in special schools by experienced teachers, and visits to industrial and other research facilities and exhibitions.

III. Some New Concepts in Physics Teaching

Physics at any level can be taught with reference to existing text books. Acceptable texts are numerous. At any medium-sized science library hundreds to thousands of volumes of specific experimental or theoretical physics text books can be found. The average teacher, however, recommends only one or two dozens of books to his class. It is not seldom that such recommendations consist of a mix of traditional standard texts combined with new concepts physics books. Of course, also misconceptions are sometimes intermingled. Generally two groups of books are in use either based on experimental physics including practical guides for laboratory work or on the other side theoretical outlines which follow the "pencil and paper" approach.

Some thirty to forty years ago films and film loops became attractive tools for a number of physics teachers and lately others created computer aided or even computer designed physics courses. The requirement of present-day physics in an integrated science teaching manner made it necessary in particular for the introductory courses to employ the best possible didactic means. A new specialization evolved called "didactic of physics". One interesting experience was reported by C.B.A. McCusker from the University of Sidney. In 1969 the School of Physics of the University of Sidney offered to its 1650 enrolled students two parallel physics lecture courses, the first one in the old traditional manner with the teachers directly interacting with the students, while in the parallel course the lectures were presented by video tapes. 210 students enrolled for the course in the traditional life-lectures, while 1440 students took the TV-video-lectures. At the end of the year 43 percent of the 210 students who attended the traditional courses passed the exams, while out of the 1440 students who attended the TV-lectures 70 percent passed successfully. From this experience it was concluded that the future possibilities in TV-teaching seem to be enormous, in particular if a proper program can be relayed by a synchronous satellite easily reaching a whole continent.

At many international gatherings, but also on national levels the role of experimental work in physics education is vigorously debated. The defenders of the experimental approach point out that physics is an experimental science and therefore practical experimental work should play the most important role in physics teaching at all levels. Only students who have the opportunity to handle materials themselves become curious to experiment and to observe. At upper levels experimental set-ups must become more sophisticated to continuously challenge the learners' curiosity. As physics advances to the university level the concepts diverge and seem to get a specific signature of a particular university. The concepts become manifold. Just to name a few: They are called the open laboratory for a laboratory which is open and available to all students at all times of the day; a self-based laboratory with personalized systems of instruction; the so-called instrumented laboratory; the divergent laboratory; and finally the project work-oriented laboratory.

Institutions who have been embarking on integrated science education have experienced its strength and limitations despite of its scope and wide methodologies. In particular case studies it was pointed out that by separating the information provision from the decision making it was believed that the information may be made more reliable. Students have a more detached perspective and different values and more time for gathering information. The ultimate strength of the system depends on the belief that decisions are better for being based on the maximum of relevant information and when being made after alternatives have been properly explored. Contrary to current popular belief an integrated education is bound to produce some disappointments. Sometimes the expectations are too high and it cannot be avoided that logistics and politics play big parts in decision making.

In summary the integrated science teaching approach should on the introductory level show that physics has both an experimental and theoretical character with some limitations. A physicist tackles problem situations employing different techniques and it should be recognized that the observed phenomena can normally be summarized and explained by physical laws. The educational aim is achieved, if the students accept physics and are convinced that physics can explain how nature behaves and that all technical advancements are somehow connected with physical principles.

IV. The New Teaching System "Physics in 700 Experiments"

Recognizing that in many instances physics and natural sciences as a whole are often disliked by some students because they have failed to see and thus have not understood the basic natural science phenomena and noticing that proper experimental equipment is not always available for high-school or introductory university courses, a project was started in 1973 to produce properly filmed physics experiments. Other aspects to launch the project were the knowledge that the results of a good educational system depend to a great extent on the teaching quality of demonstrating basic experiments. It is common knowledge that good demonstrations make heavy demands on lecturers, demonstrators and their technical assistants. Quality physics courses require a considerable investment in personnel, in finance for the procurement, maintenance and operation, particularly of the costly apparatus and the requisite consumable items. Time-consuming preparations and suitable laboratory space are other requirements. Even under optimum conditions the success of certain demonstrations cannot at all be guaranteed. In crowded large lecture halls quite often students in the back rows cannot see clearly what is being demonstrated in front.

The project aim for an ideal demonstration was defined to be:

1. Each experiment must be faultlessly demonstrable and reproducible in all its phases during the same lecture without

diverting the attention and reducing the concentration of the audience and without interruption.

2. All those present must be able to see the proceedings equally well.
3. The commitment of resources to personnel, capital equipment and consumables must be reasonable.

These conditions can be fulfilled by the use of cinematic or equivalent techniques. Individual physical phenomena have been available on film or loops for many years. Moreover, a number of lengthier, more detailed films with commentaries have been produced. The general introduction of teaching films into lectures has, however, not yet occurred because on the one hand there existed insufficient systematically compiled film series on selected basic experiments, and on the other hand, no really ideal projection equipment was available.

A series of teaching films for regular use in lectures can only be successfully constructed if it completely covers the several elements of the subject matter and meets the above criteria. Individual films - even if well produced and interesting - can as little embrace the whole subject matter as a single volume of a dictionary or a single chapter in a text book. A complete adaptation of experimental physics on the basis of filmed demonstrations only appears possible if all basic phenomena are put on film in such a way as to make maximum impact on the students and if film projectors offering a whole range of special effects are available.

To have the greatest effectiveness, films should be as short as possible. Lengthy titles, long winded introductions and conclusions, tedious repetition of certain phrases and dwelling too long on particular aspects of an experiment simply add to the length of the films without improving their efficacy. They increase costs unnecessarily whilst shortening the time available for the lecturer to make his own contribution. Of sole importance is the accurate visual presentation of the experiment. Another criterion is that the films should include sound, but only where it is associated with an experiment and adds to its understanding. There should be no commentary; only then is the lecturer himself able to adapt the film to the attainment level of his audience by providing his own commentary bringing out those aspects of the experiment most appropriate. Under the above conditions the filmed experiment is not dependent on the teacher's language. English, French, Russian, Chinese, German and other languages can equivalently be used. Also the level of explanation either elementary or advanced depends only on the teacher and the level of his audience.

A further criterion is the usually time-consuming and distracting film load and threading of single films during the lecture. Therefore, a number of films in reasonable combination should always be available by one single loading for selective projection. This will prevent an exchange of the films during the lecture - especially in a darkened room. Nevertheless, time delays for tracking the desired film sections and, in the case of repetitions, for rewinding, have so far been accepted.

The ideal projection equipment should permit a number of new possibilities not normally available in simple systems. For instance, apart from the normal speed of 24 or 25 frames per second, it should be possible to show a single phase of an experiment in slow motion with only a few frames per second or, alternatively, speeded up many times, and each of these speeds should be possible with the film running in either direction. It would also be advantageous to be able to stop the film at any required position and project a single frame thus obviating the need for a separate slide projector. Finally, the ideal projector for teaching purposes should incorporate a device enabling the selection of any desired film from a collection of many, as well as the repetition of each phase of an experiment, as often as required, within seconds so as not to lose either time or interest of the audience. These possibilities are not available with conventionally designed projectors.

"The New Teaching System" fulfils the preceding conditions as closely as practicable and permits the adaptation of time honoured teaching methods to the more effective conditions of the modern classroom.

The New Didactic System consists of:

a. the book

b. the new teaching films

c. the video discs

d. the LaserVision player

e. the control desk and the code table

f. the TV-monitor or a large electronically enhanced screen projector and/or back projection equipment.

a. The book:

The book "Physics in 700 Experiments" describes, for each of the 713 experiments listed, the arrangement of the apparatus and its method of working as well as, on an elementary level, the fundamental physical relationship. References are given to supplementary literature. The German version of the book was published in 1977 and the first English translation appeared in 1981. At that time only film versions in 16 mm and 70 mm formats existed. According to the format selected the film strips were then shown using a 16 mm projector or, in the special 70 mm format, using a projector specially developed for this large format.

The 70 mm version consisted of a high-strength polyester film on which six film strips of the 16 mm version were arranged one above the other. A special projector permitted running from left to right and from right to left. The area of an individual frame was about twice as large as that used in Super-8 mm films. Each of these Multifilm strips contained about 65 experiments and required a projection time of about one hour. The Multifilm strips were housed in a magazine and could only be used with the "Multifilm Projectomat". The projector had several functions such as the ability to run forwards and backwards at speeds varying from one to hundred frames per second and, by pressing a button, being able to hold an individual frame at any time. The electronic control allowed a rapid call-up of any of the experiments in the Multifilm strip. Once the magazine was inserted to be ready to project any desired film, it was only necessary to push buttons on the key-board corresponding to its 5-digit code numbers. The first two digits of the code number indicated the strip on which the filmed experiment was to be found and the last three digits gave its position along the strips in seconds. For rows one, three and five - running from left to right - this was between 000 and 630 and for rows two, four and six - running from right to left - it was from 630 to 000. It was under this context that format, experiment number, title and code number of the films "Physics in 700 Experiments" are listed at the beginning of the book. Some experiments contain sound. The indication for it is a capital S.

The book covers the following sections:

129 experiments on point kinematics and the mechanics of solid bodies

56 experiments on fluid and gas mechanics

82 experiments on vibration and acoustics

56 experiments on heat and temperature

70 experiments on electricity and magnetism

110 experiments on electrodynamics

53 experiments on atomic and nuclear physics

146 experiments on wave and geometrical optics and

11 experiments on quantum physical effects.

Proposals have been received to translate the book into other languages such as French, Spanish and Chinese. The 713 experiments are described on 733 pages. The book is illustrated with 381 figures and contains 76 tables.

b. The new teaching films:

The new teaching films are 713 separate films illustrating the 713 experiments described in the book. The films show individual characteristic physical phenomena, are without commentary, which is the duty of the lecturer, and carry throughout the original sounds where they are necessary to understand the experiment. These new films have been produced on 16 mm or 35 mm colour film by professional film and camera crews in collaboration with physicists actively involved in research and teaching. Events of extremely short duration were rendered visible by means of high speed cinematography; those not normally optically realizable were made so by the use of cartoons. Instead of film titles the new teaching films carry only the consecutive experiment numbers used in the book. A green field lasting for about one and a half seconds is shown at the beginning and a red one of similar duration at the end of each film sequence. The longest experiment lasts about three and a half minutes, the shortest about seven seconds. For the sake of better handling and taking advantage of latest technology the 713 films are now available on 22 video discs.

Nearly two and a half years were required to properly set up the experiments and to produce the colour films. At normal speed the running time of all films exceeds eleven hours. In order to allow selection of the best sequences each experiment was filmed several times.

c. The video discs:

The video discs (30 cm diameter) hold the vision and audio information in analogue form. Each single-sided disc contains vision and audio information of 48600 frames (discs 1 to 4) or 45360 frames (discs 5 to 22). Every individual frame is consecutively coded with a five-digit number from 00001 to 48600 or 00001 to 45360. The life of a video disc far surpasses that of other video and audio storage media. The quality of the reproduction is also better. Retrieval of the video and audio signals is achieved without contact with the disc and consequently is not subject to wear and tear.

In the disc production process information is assembled on to a master tape in a similar way as done in other video productions. Then a glass disc master is made, from which working discs are produced through a specially developed replication process. In the LaserVision mastering process the information from the master tape is encoded into LaserVision standardized format. In a laser beam recorder this is recorded optically on a photo-sensitive coating on the surface of a glass disc. Photographic development and evaporation of a silver layer on to the developed surface produces the LaserVision master disc. Then, by electro-plating a zinc-nickel replica is produced from the master disc.

Separated from the master disc the replica is mounted to one face of the mould in the injection moulding machine. Injection moulding is used rather than pressure moulding because of its innate precision and speed. This makes it possible to mould the two sides of the disc, if required, alongside each other in the same production unit. After injection moulding the disc is silver coated, cleaned, checked and passed to a buffer's store which allows for possible differences in production rates of the two disc sides. From the injection moulding stage onwards the whole process is carried out in one single machine with automatic processing and handling.

The finished disc looks highly reflective as a consequence of the reflective coating. One of the advantages of the laser disc is the much greater information density. The distance between two information elements on the laser disc is about sixty times smaller compared with a normal record. All audio and visual information are contained on the laser disc in a coded form and placed on a spiral-like track. The track contains a sequence of microscopically small cavities of 0.4 micrometer width and 0.1 micrometer depth. Distance and length of these cavities are changing as a consequence of information contained. These engravings are called "pits". When playing the discs a 1 mW laser of the helium-neon or semiconductor type follows the spiral track.

Where-ever the laser light passes over an engraved cavity, the parallel light of the laser beam is reflected differently than on the plane surface. A photo-diode measures these light variations and allows to reproduce the original video or audio signal. The average distance between two tracks is 1.6 micrometer and this explains the enormous information density of a laser disc.

d. The LaserVision player:

The LaserVision player is based on a laser pickup system. It is designed for professional use and is easy to look after. Operation is simple: the video disc is easily loaded by hand and is then ready to play. Starting the player and selecting the various functions is accomplished by using the control desk.

So far two disc drives - Philips VP 835 and VP 405 - were tested. Both disc drives feature modular construction for high reliability, intensive use and front-loading of the laser discs. Moving pictures from very slow motion to scanning speed give the instructor great flexibility to explain the experiment to his audience. Using the still-picture mode it is possible to discuss in detail the experimental set-up. Each picture frame can be accessed in less than one second and for interactive operation the proper control hardware is available.

As soon as the disc is inserted on the turntable the disc will build-up to a speed of 1500 rpm in approximately ten seconds. When the player is switched off as well as when the end of the disc is reached, the scanning lens returns rapidly to its starting point and the laser is switched off. It takes about ten seconds until the cover opens and the disc can be removed. To prove the superiority of the laser disc against a normal film one single frame was played continuously for twenty-four hours. No wear-out signs were observed and no picture quality reductions were seen. The player-system VP 405 operates on fifty and sixty cycles, while VP 835 brings optimal results only with fifty cycles of the mains supply. The VP 405 has an RS232-C interface to the controlling computer and a wired RC-5 remote control. An Euroconnector provides direct RGB, composite video and audio connections to the color TV monitor and stereo amplifier. The connection rate via RS232-C interface is adjustable to 1200 or 9600 baud. Other improved features are an AlGaAs semiconductor laser with 3mW output and an electronic time base correction using a charge-coupled device.

e. The control desk and the code table:

The control desk is a minicomputer with keyboard which transmits the orders given to it either by cable or infra-red signal. If, for example, it is required to reproduce a certain experiment stored on the disc, it is only necessary to enter its code number on the keyboard. The five digit number entered then immediately appears on the monitor or projection screen; the chosen experiment is run within seconds of the start key being operated. At the end of each experiment the title numbers of both the experiment shown and the next one on the disc appear until the next film is called up on the keyboard. The running of an experiment can be halted at any time during the demonstration by simple operation of the stop key. The last frame shown then remains on the screen as a still and gives the lecturer as much time as he desires for his own explanation. A simple key operation is sufficient to restart the demonstration either forwards or backwards if the experiment is to be discussed further. Each experiment, each individual phase of an experiment as well as each single frame stored on the disc can easily be called up by keying in the corresponding code number. As well as entering the code number, the keyboard can select all the necessary functions such as start, stop, pause, forward and reverse, fast or slow, down to individual frame sequences. In addition, the number of the frame being shown can be requested. Automatic loops can be created between all frames of the disc.

The code table finally displays clearly the five-digit coded number of the beginning of every experiment on the video discs.

f. The monitors:

The experiments stored on the video disc can be shown on one or more TV-monitors or on an electronically intensified large screen display or, for cramped or daylight conditions, on mobile back projection equipment with a collapsible screen of approximately 1.70 m diagonal measurement.

As from September 1983 at the Institute of Experimental Physics, University of Vienna, a color video projector VPH-722Q is used in connection with the LaserVision player VP 835 to show the experiments recorded on the 22 video discs with good success. Recently a more powerful projector, the VP 1010 together with the player VP 405 is in use. With these equipments all experiments can be shown at day-light conditions. Significant improvements in acceptance of physics for non-physics students like pharmaceutical, medical, biology and biochemistry students have been observed and the failure rate for the required exams was drastically reduced. Five years of experience with this new teaching system are now available. So far no significant negative aspects were experienced and the positive aspects lend itself to recommend that teaching with this new concept in other fields could equally benefit.

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