United Nations Educational, Scientific and Cultural Organization

Our closest relatives on the brink of extinction p. 20

A World of SCIENCE

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EDITORIAL

Why physics? Why now?

One hundred years ago, a young man working in the Patent Office in Bern, Switzerland, published a series of scientific articles. These introduced revolutionary ideas on fundamental questions related to the existence of atoms, the nature of light, the concepts of time and space, energy and matter. They opened up a whole new world composed of the infinitely small (particles), the infinitely large (the cosmos) and the infinitely complex (the states of matter). The name of this young man was Albert Einstein and his theories would lay the foundations for transistors, computers, lasers, televisions, magnetic resonance imagery in medicine and space travel.

Ambassador Moleko of Lesotho evoked this Miraculous Year, as it is known, when presenting a resolution for an International Year of Physics in 2005 to the United Nations six months ago.

The International Year of Physics celebrates the genius of Albert Einstein. But the Year is as much forward-looking as commemorative. If anything, we have an even greater need of the physical sciences now than ever before. How else will we solve the major problems of the 21st century related to energy production, environmental protection and public health? But first, we will need to persuade dubitative politicians that the technologies they will need tomorrow are the basic research of today.

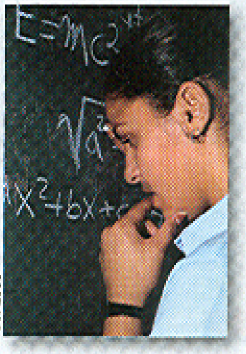
More than 60 countries around the world are preparing special events to celebrate the Year, of which UNESCO is lead agency and one of the co-ordinators within an international steering committee led by the European Physical Society.

The Year is being launched by a conference on the theme of Physics for Tomorrow from 13 to 15 January at UNESCO Headquarters. Open to the general public, the conference will focus on the role of physics in society and its impact on everyday life, the influence of Einstein on the science of the 20th and 21st centuries, the teaching of physics and its links with other disciplines.

Given the troubling – and in some cases growing – disaffection for physics among the younger generation, the lead story in this issue looks at how teaching methods are evolving towards activity-based tuition, a promising new approach.

A World Conference on Physics and Sustainable Development in Durban from 31 October to 2 November will round off the Year, sponsored primarily by UNESCO and its Abdus Salam International Center for Theoretical Physics, the South African Institute of Physics and the International Union of Pure and Applied Physics. Approximately 500 physicists and policy-makers from around the world will meet to discuss the ties between physics and economic development, health, energy, environment and education. The conference is expected to come up with an agenda for action that the international physics community can implement collectively.

W. Erdelen
Assistant Director-General for Natural Sciences



Physics without tears

Physics has never been a popular subject. Students tend to conclude that, on balance, physics requires too much work compared to the career options it promises. Most physics graduates, and especially those in developing countries, tend to end up as poorly-paid university or secondary school teachers. As a result, few students choose to major in physics. While data for most countries are incomplete, the available statistics do tend to show that the percentage of physics majors out of total university enrolment remains low.

The good news is that teaching methods are evolving. Today, the accent is being put on activity-based tuition that engages students in the learning process. Not only are there signs that students are enjoying physics more than before but recent studies also show a marked improvement in student performance when interactive teaching methods are applied.

Why is it so important to improve physics teaching at university? The answer is obvious. The physics students of today are tomorrow's scientists, engineers, medical doctors and teachers at the secondary and tertiary levels. Even future economists, psychologists and writers usually take an introductory course in physics. At Columbia University in the USA, this course has been affectionately dubbed 'physics for poets' by students. The fact is that a basic knowledge of physics is a key component of a well-rounded education. A university graduate who understands nothing of the forces behind natural phenomena like lightning or gravity goes through life with a handicap. He or she is equally handicapped when it comes to understanding the modern world. Herwig Schopper gives a poignant example of this (p.14) when he tells how doctors have had to drop the word 'nuclear' from the term of imaging with nuclear magnetic resonance to avoid scaring patients – whose misgivings are born of ignorance.

An article published by the Forum on Education of the American Physical Society in 2002 contends that the physics major in the USA is an endangered species. The authors write that, 'In 1999, … the absolute number of physics majors reached the lowest point since the end of the 1950s' (see box).

Edmund Zingu, President of the South African Institute of Physics, gives an idea of the situation in Africa in *Physics Today* (January 2004), when he writes that 'some of the poorest countries have gross enrolment rates [in science at secondary school] of between 5% and 10%. It is therefore not surprising', he concludes, 'that the development of a physics tradition, and the corresponding public investment in physics in those countries, is limited, or even nonexistent.'

In Latin America, 'despite continued growth and improvement, the production of trained physicists remains low', regrets José Luis Morán-López in *Physics Today* (2000). Professor of physics at the University of San Luis Potosi in Mexico, he calculates that the region counts 'at most 40 000 physicists [with at least a Bachelor's degree in physics]' out of a population of 500 million. He concludes that 'clearly, several Latin American institutions offer very good undergraduate and graduate programmes but the number of graduates is insufficient to serve the needs of the region'.

José Luis Morán-López has divided Latin American countries into four groups based on the population of physicists and overall scientific output. The most developed group is in yellow, the intermediate group in blue, the third group in red and the few remaining countries, those with a negligible physics community, in grey

Publish or perish!

It follows that, with few students majoring in physics, the numbers of physicists and physics teachers are also low. In the developed world, the few who do complete a degree and go on to become physicists usually find employment either in the university sector or in industry. In the South, most physicists are employed in universities. In developed and developing countries alike, those who do work in universities are expected to teach while at the same time conducting up-to-the-minute research, or research on a specific topic. For them, research is the key to a successful career, not teaching. 'Publish or perish' is a well-known maxim among physicists, whose success is generally measured in terms of publications; no such yardstick of success exists in teaching.

Moving away from the chalk-and-talk method

Does a degree in physics make a good physics teacher? 'Physics teachers generally teach as they themselves have been taught', comments Lillian McDermott, the multi-awarded pioneer in

Physics Education Research (PER) from the Department of Physics of the University of Washington (USA). 'In recalling how they were inspired by their own experience with introductory physics, many instructors tend to think of students as younger versions of themselves.' Moreover, McDermott has shown that university physics courses do not provide the preparation that teachers need. Many physicists have been taught by the chalk-and-talk or lecture method. PER studies have demonstrated that the traditional or lecture mode of teaching has been ineffective. The conceptual and problem-solving test results from a 6000-student survey of mechanics test data of introductory physics courses by Richard Hake at the Indiana University (Bloomington, USA) published in 1998 'strongly suggest that the classroom use of interactive engagement methods can increase mechanics-course effectiveness well beyond that obtained in traditional practice.' The traditional method of teaching is generally held responsible for the unpopularity of physics among students. The chalk-and-talk approach has failed to communicate the excitement and joy of discovery experienced by those who work in the field.

The situation in physics teaching in many countries, especially in the developing world, is a complex problem. Most physics teachers in universities and secondary schools either lack the appropriate educational background in physics or have only a tenuous hold on their conceptual understanding of physics. Science education experts believe that the high percentage of pupils who fail in physics and the growing aversion for the subject clearly demonstrate that teacher training means much more than simply lecturing future teachers in physics. The lack of a solid grounding in the subject also needs to be addressed. Many physics departments lack a consistent approach to developing and maintaining their undergraduate teaching laboratories. As a consequence of the 'publish or perish' dictate, research laboratories are given more importance and resources than those required for teaching. When physics teachers do invest the extra time and energy to make their teaching more interesting, their efforts often go unnoticed, earning them no appreciation and no recognition. To compound the problem, there are physics graduates who teach without ever having benefited from any laboratory experience themselves.

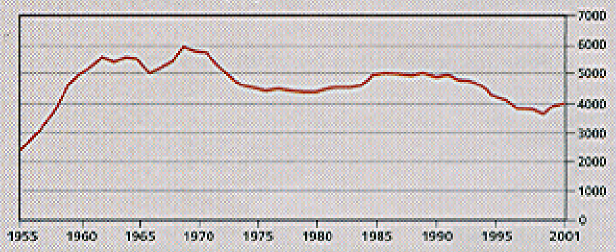
Notably in the USA, PER groups have been established over the past twenty years in several university physics departments to look into innovative approaches to teaching and student learning, including interactive engagement. Essentially, the method is activity-based to engage students in the learning process.

UNESCO has initiated a number of projects to regenerate university physics teaching. Regional physics education networks were established under the auspices of UNESCO in the 1980s. Among these, the Asian Physics Education Network (ASPEN) has been run over the years through support from UNESCO's Jakarta Office. ASPEN has organized various activities implicating countries in Southeast and East Asia, notably Japan, China, Republic of Korea, Thailand, Malaysia, Philippines, Australia, Laos and Vietnam.

The end of a downhill slide for physics majors in the USA?

If Bachelor's degrees have climbed steadily in the USA over the past half-century from quarter of a million in 1955 to 1.2 million in 2001, the progression in those majoring in physics has been a more bumpy ride. As can be seen from the graph below, numbers rose steadily in the 1950s and 1960s to a peak of 6000 in 1969 before falling off to fewer than 4000 by the end of the century. Numbers have begun picking up timidly again since but, even so, only 3.4 of every 1000 Bachelor's degrees were awarded in physics in 2001.

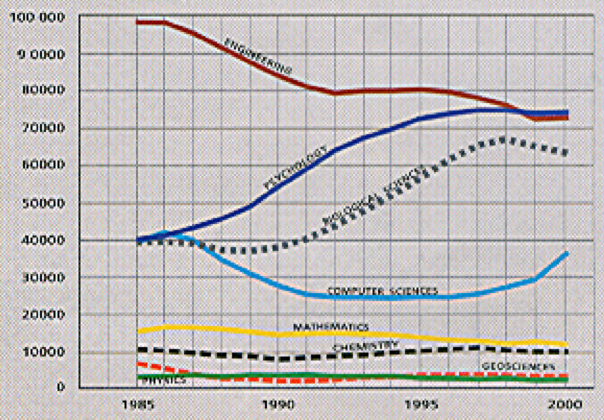
Bachelor's degrees awarded in USA in physics, 1955–2001



Source: American Institute of Physics Statistical Research Center, Roster of Physics Departments and NCES Digest of Education Statistics

From the graph below, we can see that the 1990s was a volatile decade in terms of undergraduate education. Many calculus-based fields, such as physics, engineering and mathematics, lost students at different points during the decade. This seems to be at least in part because of the ever-greater choice of course options. The two fastest-growing fields in the 1990s were biology and psychology, both of which were strongly popular with women (75% of psychology majors were women). In 1998, about 55% of all Bachelor's degrees were earned by women, a trend the US Department of Education projects will amplify, with women representing 58% of the Bachelor's class in 2010. In physics, however, women only passed the 20% mark for the first time in 1999. In 2001, they represented 22% of the physics undergraduate class.

Bachelor's degrees awarded in USA by discipline, 1985–2000



Source: American Institute of Physics Statistical Research Center, compiled data from National Science Foundation WebCASPAR Database System, March 2002.

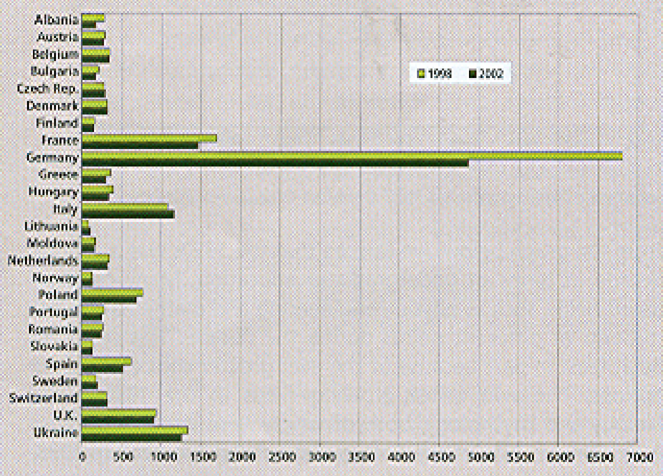
Europe's physicists of tomorrow

There is a general impression in Europe that the number of physics graduates is decreasing but is this really so? No Europe-wide statistical study had been conducted until the European Physical Society took it upon itself to determine whether there was indeed a disaffection for physics at the tertiary level.

The Mapping Physics Students Across Europe (MAPS) project submitted its first report to the European Commission in April 2004. The report shows that the number of physics graduates shrank by 15% across Europe between 1998 and 2002. Half of countries recorded a drop, notably the populous countries of Germany (-28%), Spain (-16%) and France (-14%) grouping 200 million Europeans (see graph below).

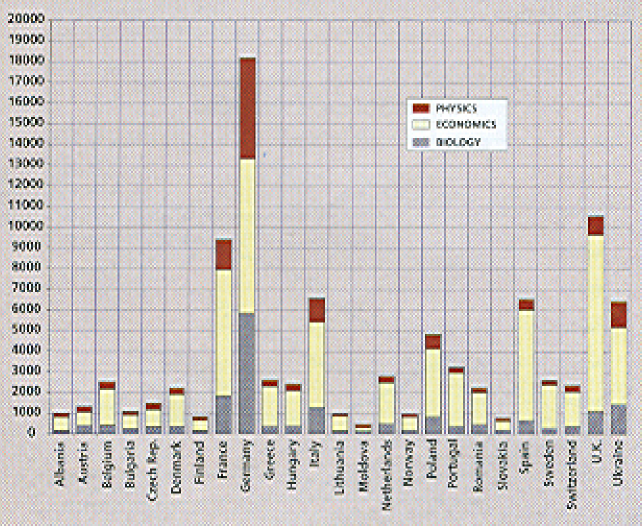
Yet, Europe will need an additional 500 000 scientists in all fields if it is to reach its target of a European Research Area spanning 30 countries or more by 2010.

Physics graduates in 1998 and 2002



Physics graduates in 2002

Compared to graduates in biology and economics



The MAPS report may be downloaded at: www.eps.org

In 1990, UNESCO launched the University Foundation Course in Physics (UFCP) to give first-year university teaching in physics a boost by pooling expertise from developing and developed countries alike to help universities – especially those in developing countries – improve the quality, effectiveness and relevance of their introductory physics courses. While emphasizing the need for more laboratory work and topics on contemporary physics, UFCP recognizes that not all topics can be taken up with equal rigour and effectiveness.

The project took off in Asia thanks to ASPEN, which provided experts from China, India, Japan, Australia and the Philippines. Their participation resulted in the production of a textbook and modules on selected topics in contemporary physics, as well as laboratory manuals and instructional materials on video and computer simulation software.

Working in groups of two or three, participants in an active learning workshop in Sri Lanka are studying the motion of a falling object in real-time

UFCP was a pioneering effort to break away from the traditional approach to first-year physics teaching. One off-shoot has been for different countries to take advantage of the international collaboration to develop their own instructional materials.

Physics education networks established under the auspices of UNESCO in Latin America and in Arab and African countries have not fared as well as their Asian counterpart. But that could be about to change. Since the VIII[th] Inter-American Conference on Physics Education co-sponsored by UNESCO in Cuba in July 2003, plans are afoot to revitalize the Latin American physics education network. On another continent, physics teachers from seven countries in Africa have formed an electronic group to facilitate the online exchange of news and information on the active learning method in the wake of the first UNESCO regional workshop on the technique in Ghana in October 2003 (see photo).

Hands-on learning in physics

UNESCO and ASPEN have been organizing hands-on workshops demonstrating the active learning technique

A bicycle wheel can be used to demonstrate rotational force or torque and its relation to angular velocity and momentum

In a training course for resource persons in Manila (Philippines), trainees were presented with all kinds of locally available devices and materials, both computer and non-computer based

since 1996. Together, they have also developed innovative techniques in co-operation with PER experts from the USA and hands-on curriculum material. Workshops have been run in Laos, Australia, Malaysia, the Philippines, Republic of Korea, Sri Lanka and Vietnam.

Moreover, with UNESCO support and in co-operation with ASPEN, active learning modules on topics in mechanics have been developed and compiled for free distribution. These workshops have demonstrated that many physics teachers are keen to improve their teaching methods.

Building on the ASPEN experience, the recent UNESCO workshops in active learning organized in Africa in collaboration with the Society of African Physicists and Mathematicians have fostered the use of laboratory work and hands-on activities in physics classes to improve conceptual understanding of physics and promote innovative modes of content delivery, especially those developed in the USA by McDermott, Priscilla Laws of Dickinson College, Ronald Thornton of Tufts University and David Sokoloff of the University of Oregon.

UNESCO has put together a team of resource persons to run the workshops who identify with physics teachers and understand conditions in developing countries. ASPEN members play a key role in the team, which is developing learning materials and activities with emphasis on South–South collaboration. Resource persons from farther afield are also being primed to run workshops in other languages; they undergo training and evaluation in using and developing active learning materials, including designing hands-on activities and formulating probing discussion and assessment questions.

Caring about students

The active learning method, or 'interactive engagement', endeavours to match the teacher's strategy with the student's learning style. The active learning environment is generally characterized as being student-centered and activity-based with recourse to computers and other equipment.

Students are actively engaged in the learning process. They work in groups with materials and equipment, making predictions and observations, exchanging ideas with classmates and teacher, asking and answering questions. They use the results of their work to make mathematical descriptions and construct theories. In the process, they are developing scientific reasoning skills and learning the underlying principles and concepts. They then cease to be mere receivers of information.

It falls to the teacher to prepare the learning environment by choosing the experiments, exercises and discussion questions. By keeping lectures to a minimum and asking the students questions, the teacher guides the class through the reasoning necessary to construct concepts. In so doing, the teacher acts as facilitator, giving up her/his role as the source of all information.

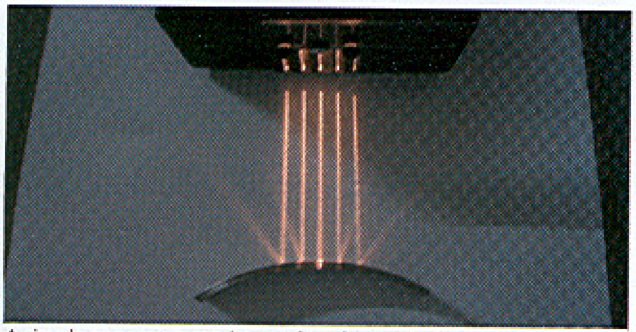
The Asian Physics Education Network

ASPEN was established in 1981 on the recommendation of the UNESCO Consultative Committee Meeting in Khon Kaen (Thailand) attended by representatives from Afghanistan, Australia, China, India, Indonesia, Korea (Rep.), Malaysia, Papua New Guinea, Philippines, the former USSR and Thailand.

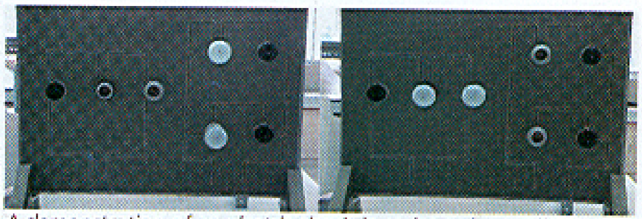
ASPEN promotes the overall development of university physics education in Asia and has established a programme of co-operation among members, to whom it disseminates information.

ASPEN operates through a network of National Points-of-Contact (NPCs) nominated normally by the National Commissions for UNESCO. The network collaborates closely with UNESCO's physics programme at Headquarters and in the field through UNESCO's regional offices for science and technology in Jakarta and New Delhi.

The Co-ordinating Board is headed by a Chair and Vice-Chair and made up of NPCs of seven member countries and a UNESCO representative. Every five years, the ASPEN General Assembly meets to take stock and elect new officers to the Board. At the last General Assembly in Sri Lanka in December 2002, membership comprised Australia, China, India, Indonesia, Japan, Korea (Rep.), Laos, Malaysia, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam.



A simple apparatus can be used to demonstrate image formation by curved mirrors. The curved mirror above is made from aluminium and the ray box has been built using the periscope principle



A demonstration of an electric circuit in series or in parallel can be constructed using a wooden board, electric bulbs, batteries and a switch. The apparatus can be used as an interactive demonstration in a lecture. By comparing the brightness of the bulbs connected in series or in parallel, students can see for themselves the difference between series and parallel circuits in terms of current and voltage, and the effect of switching the circuit on or off. This demonstration gives the student a real experience of electric circuits beyond the blind note-taking and copying of diagrams

Assessment and evaluation are an essential part of the active learning approach. It is important to determine how well the students are taking in physics concepts. The development of active learning curricula through physics education research has gone hand in hand with the design of standardized assessment instruments to probe conceptual understanding. Three tools of note are the Force Concept Inventory, the Force and Motion Conceptual Evaluation, and the Conceptual Survey of Electricity and Magnetism. These assessment tools differ from the usual approach of requiring students to manipulate formulae or answer questions on the basis of memorization.

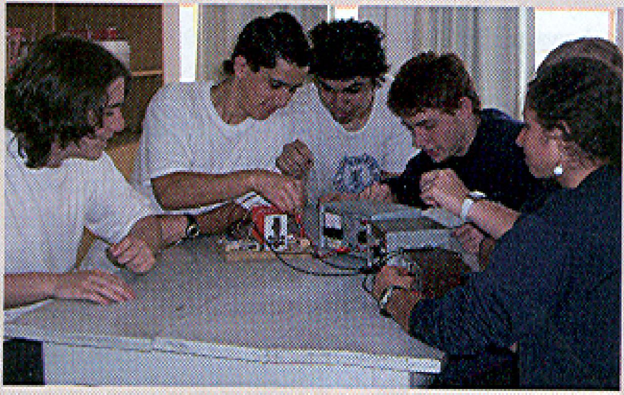
One size does not fit all

There can be no 'one size fits all' approach. To be effective, active learning modules in physics need to take into account the resources available in the university and the cultural context. This does not mean that materials that have been developed to date and evaluated overseas are not valuable but some adaptation will be necessary. The Force and Motion Conceptual Evaluation, for example, which is used to probe conceptual understanding of

Teenagers tackle their country's energy problem

Energy is one of the scientific concepts most frequently found in school science courses, even at the primary level. This is only natural, given that we are surrounded by energy in one form or another. One of the first things children learn at school is that energy cannot be created or destroyed but only changed into another form. They learn that the sun emits solar energy but that we can only make use of that energy by converting it into electrical energy using solar panels, or that coal contains chemical energy that can only be converted into heat energy by burning the coal. In other words, they learn that any form of energy is only as useful as our ability to harness it. Yet, when pupils are taught about the concept of energy without being able to put theory into practice, the lesson tends not to sink in.

In Uruguay, the prolonged drought of 2004, in a country where hydroelectric power is normally sufficient to cover 80% of the country's electrical demand, inspired teachers at the Instituto Ariel Hebreo Uruguayo to design a practical, even topical, project for their third-year classes. The idea was to show the 16-year olds how important it was for a country to develop a contingency plan within its energy policy to prepare for unforeseeable extreme weather events like drought. Incorporated in the school project were elements taken from physics, chemistry and biology. The teachers encouraged pupils to explore the concept of energy, helping them in particular to grasp as abstract a concept as the definition of capacity.



Here, pupils at the Instituto Ariel Hebreo Uruguayo are using an ammeter and a voltmeter to observe the changes in current and voltage in a simple DC-powered electric circuit

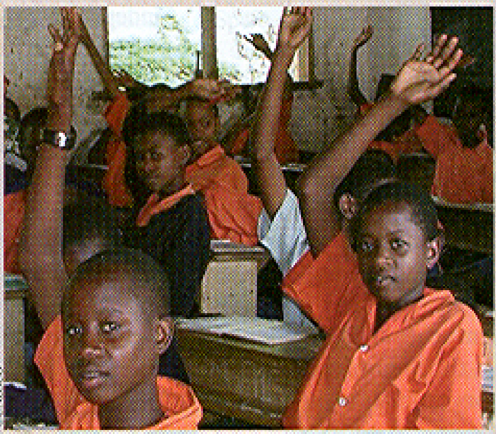
The teachers organized a debate using a didactic approach developed by the Organization of Ibero-American States and Oviedo University in Spain. In this case, the debate centred on Uruguay's recent energy crisis. The fictional controversy the teachers chose concerned a proposal by an enterprise to install a nuclear power plant. Pupils were asked to play different roles and defend conflicting points of view. They were asked to develop arguments based on information in real and fictional handouts from their teacher, together with any other details they could unearth on the costs, risks, etc. of this means of generating electricity. They were then asked to present alternatives. The group arguing against the nuclear power plant came up with proposals for solar cells, biogas and windmills. Once both sides had presented their arguments, the floor was thrown open to questions before the class voted to decide which side had won.

For details, contact physics teacher Sergio Gunther: sgunther@adinet.com.uy; www.institutoariel.com.uy/

For details of UNESCO's science education programme in Latin America, contact Beatriz Macedo: bmacedo@unesco.cl; or Raquel Ejgenberg: arielej@movinet.com.uy

Helping girls shake off gender-stereotyping

Ms Koech has been teaching physics at Pangani Girls' High School in Nairobi (Kenya) for the past five years. Physics is Koech's passion. Yet teaching physics is a daily struggle to combat the real and perceived fears of physics among girls. Koech believes that girls can succeed and even enjoy physics. Drawing on everyday life experiences, Koech is never at a loss for physics examples: she uses walking upright to explain gravity, lifting an object to explain mass, the distance moved to explain force and so on. 'Physics is so practical and real', she enthuses. 'You explain what you see. In fact, with an understanding of basic concepts, learners can explain and analyse observations according to principles and laws of physics.'



Girls at Pangani High School

Koech speaks of the phobia for physics among girls, especially when it comes to mathematical equations. This fear is fuelled by misconceptions vehicled by family and friends. 'In our family, we believe that girls cannot perform well in sciences,' one pupil sighs. The girls' negative attitude towards science starts at home, where they are discouraged from taking science subjects. One third-year pupil recalls, 'I was being discouraged by my family and friends that physics was a hard course with so many graphs and calculations. My family wanted me to take history or geography instead'.

Girls tend to dissociate themselves during practical sessions, considering mechanics, electronics and electricity to be masculine domains. 'Parents encourage their young boys to make little cars and construct things while encouraging their girls to play "mum" by cooking and taking care of the baby. This affects girls' development and attitude towards science', regrets Koech.

'If learners can relate concepts from mathematics to principles in physics, they tend to overcome their fear of physics and perform better', says Koech. A third-year pupil confirms this. 'Physics is fun and interesting once you are able to relate it to mathematics'.

Inspired by their teacher's love of physics, the girls have started a school Physics Club which is enjoying growing popularity.

For details of UNESCO's science education programme in Africa (in Nairobi): Susan.Nkinyangi@unesco.unon.org

Newton's Laws of Motion, was developed originally in a temperate country and in American English; it is currently being adapted to the context of tropical countries, where teachers' first language is not English. The original version describes a sled on ice and refers to a person wearing spiked shoes standing on the ice and applying a force to the sled, which pushes it along the ice. The 'tropical' version begins as follows:

> A woman works in an ice-making factory. She moves a large block of ice around the factory by sliding it along a very smooth polished floor. The friction between the ice block and the polished floor is so small that it can be ignored. The woman wears non-slip rubber-soled shoes when standing on the floor, so that she can apply a force to the ice block and push it along the polished floor.

Computer use is desirable, where possible, since computers enable students to acquire data and draw graphs providing a real-time picture of a physical event that is computer-automated. In the study of Newton's laws of motion, for example, the use of computers enables the student to control the motion of an object and observe and understand the changes in its motion.

However, as computers are not yet a familiar sight in physics-teaching laboratories, non-computer-based activities using simple, locally available materials have been developed, some of which are shown on these pages. These activities will be compiled in a training manual and disseminated before the end of 2005 both online through the ASPEN website and in printed form.

It will take a concerted, consistent approach to collaboration with committed partners to make the paradigm shift in physics teaching. Recent UNESCO activities in physics education, including those of its centre in Trieste, the Abdus Salam International Centre for Theoretical Physics, have thus brought on board the International Society of Optical Engineering, the Ateneo de Manila University (Philippines) and the University of Oregon (USA).

Rising to the challenge

Introducing the active learning method to physics teachers in developing countries will require a tremendous effort and a commitment to change. The shift from a passive learning environment to an active learning one will not be easy. Most of the hurdles on the path ahead are a consequence of the pervading traditional culture in physics teaching. These should evaporate, however, as teacher (re)training progresses and we begin to see improvements in physics education. Since collaboration among physics teachers will be central to this process and they will need to pool their ideas and experiences, the key to success will lie in whether or not physics education networks can rise to the challenge.

Minella Alarcon[1]

For details: m.alarcon@unesco.org
International Year of Physics: www.wyp2005.org

1. *UNESCO Programme Specialist, Co-ordinator of International Year of Physics*