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EDUCATION AND TRAINING IN SPACE SCIENCE AND TECHNOLOGY

Background paper 10

The full list of the background papers:

1. The Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and microgravity research and their benefits
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PREFACE

The General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of UNISPACE III will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development.

Other objectives of UNISPACE III will be as follows:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for UNISPACE III, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference, as well as in the regional preparatory conferences, with information on the latest status and trends in the use of space-related technologies. The papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and should be read collectively.

Member States, international organizations and space industries planning to attend UNISPACE III should consider the contents of the present paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

The present paper was prepared with the assistance of teams of experts from the United Nations Office at Vienna, the World Meteorological Organization, the Centre for Space Science and Technology Education in Asia and the Pacific (India), the Centre national d'études spatiales (CNES) of France, the Centre royal de télédétection spatiale of Morocco, the European Space Agency (ESA), the Harvard-Smithsonian Center for Astrophysics (United States of America), the Indian Space Research Organization (ISRO), the International Space University (ISU), the International Space Services (United States), the National Aeronautics and Space Administration (NASA) of the United States, the National Autonomous University of Mexico, the Brazilian National Space Research Institute, the Obafemi Awolowo University (Nigeria), the South African Astronomical Observatory and the University of London Observatory of the United Kingdom of Great Britain and Northern Ireland.

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SUMMARY

Space science and technology education can be pursued at the elementary, secondary and tertiary levels. In the spacefaring States, elements of space science and technology have been introduced into the science curricula at those levels. Such an innovation has not taken place in many developing countries, partly because the benefits of space science and technology have not been appreciated enough, and partly because the facilities and resources for teaching science and technology at the educational institutions in those countries are not well developed.

Education and training in space science and technology in industrialized countries have become highly interactive. In those countries, the Internet and other information technologies have become useful tools in education and training programmes at all levels. International cooperation in the areas of education and training could be encouraged to enable developing countries to develop their own education and training programmes.

The infusion of elements of space science and technology into school science curricula at all levels could serve a dual purpose for industrialized and developing countries. It could revitalize the educational system, introduce the concept of high technology in a non-esoteric fashion, and help create national capacities in science and technology in general. Moreover, all countries can take advantage of the benefits inherent in the new technologies which, in many cases, are spin-offs from space science and technology.

There are challenges in the teaching of science, both in developing and industrialized countries, but the challenges are of a higher magnitude in developing countries. The general problem confronting science education is an inability of students to see or experience phenomena being taught, which often leads to the inability to learn basic principles and to see the relationship between two or more concepts and their practical relevance to problems in real life. Added to those problems are a lack of skills in the relevant aspects of mathematics and a lack of skills related to problem-solving strategies. There are also language problems, which are more acute in some developing countries where science is often taught in a language different from the mother tongue. Over the years, industrialized countries have overcome most of the basic problems, except perhaps the psychological problems that students have about science being a difficult subject. In developing countries, however, the basic problems still linger, exacerbated by the fact that there are very few academically and professionally well-trained teachers.

Extension and outreach programmes are essential components of education and training in space science and technology. Communications skills must be developed and learned to convey scientific and technological concepts, thoughts, observations and practical results to the non-scientific communities.

Education and training in space science and technology are integral programmes of the missions of many space organizations both in industrialized and developing countries. Such educational programmes exist in the Centre national d’études spatiales (CNES) (French National Centre for Space Studies), the European Space Agency (ESA), the Indian Space Research Organization (ISRO), the Instituto Nacional de Pesquisas Espaciais (INPE) (Brazilian National Space Research Institute), the National Aeronautics and Space Administration (NASA) (United States of America), and the National Space Development Agency (NASDA) (Japan), to name a few space agencies. Each space agency has a unique mission, generally not performed by any other organizational entity within the country concerned. For the purpose of the present background paper, educational programmes in space science and technology are illustrated by reference to the educational elements within NASA.

INTRODUCTION

1. An effective system of education is essential for all countries. Within the system, training programmes develop specific skills. If a country is to use space science and technology effectively, it must have policy makers, decision makers, and administrators capable of assessing the political, social and economic implications of science and technology, scientists capable of developing and adapting the technology, engineers to design applications systems, technicians to construct and operate the systems and teachers to teach science and technology. A variety of education and training programmes will be required at various levels and with various orientations or specializations.

2. It is important to make a distinction between the terms education and training. The objectives of education are to bring the individual to an understanding of a subject, so that he or she may form independent opinions, establish priorities and understand and discuss the methodology, the techniques used and their applications. Education is concerned with the development of mental ability and of mental power, and thus with the attitude of people. The objectives of training are to teach individuals to carry out specific tasks based on an accepted methodology and for which known techniques are available. Understanding of the context is not always required; often only the ability to apply the technique is needed. Knowledge of the subject as a whole may not be necessary. Training brings the individual to a desired standard of efficiency. This is achieved by instruction and practice.

3. The specific requirements for education and training depend on the specific field of science and technology. Operational satellite systems in communications and meteorology require engineers and technicians with well-defined skills; experimental systems in remote sensing require a more flexible approach. The field of communications, with its large industrial infrastructure, may adopt satellite technology more easily than the fields of meteorology or remote sensing with their smaller infrastructure. The end-users of the satellite technology may not be aware of the satellite, as is usually the case in communications. They may receive interpreted data from meteorological satellites, or they may receive raw data from remote sensing satellites. In communications, therefore, only those directly involved with the satellite may need to be trained. In remote sensing, a very wide range of people must be trained in various aspects of the new technology.

4. National policies on education and training in space science and technology could be part of an overall educational policy. Education should be regarded as a productive investment in human resources, resulting in personal growth and development, improved social satisfaction, higher efficiency and better public services. Education and training are the indispensable complements of any investment in new technology and in expanded public services, and such investments are prime catalysts in socio-economic development. The cross-section of society requiring education or training includes:

(a) Decision makers and planners, including politicians and senior officials, who should have a general awareness of space science and technology and its practical and policy aspects;

(b) Managerial people in institutions, agencies and private enterprises, who should have a sufficient scientific and technical background to coordinate activities regarding specific applications of satellite data and to establish facilities concerned with space science and technology;

(c) Personnel carrying out satellite surveying tasks at various levels, who should receive instructions for the interpretation of imagery and digital data for mapping and monitoring in various disciplines and environments;

(d) Technical support staff, from engineers to technicians, who should be responsible for construction, operation and maintenance of facilities and equipment, and who need manuals giving instructions for performing technical tasks;

(e) Research workers, who should develop interdisciplinary approaches in their work, and who possess in-depth knowledge of several aspects of space science and technology;

(f) Teachers, responsible for the education and training of the various groups of personnel, who should have insight in scientific and technical matters and experience in educational technology and curriculum development.

5. Industrialized countries that have consolidated organizations and infrastructures need training for specific skills and education for further development, improvement or transformation of existing infrastructure. Many developing countries are still at stages of institutional development in which a relatively large number of personnel, at various levels and in different categories, are to be trained in specific skills in a short period of time. In addition, education is required to establish or modify professional infrastructures. Marked differences in the level of socio-economic and institutional development occur between regions and countries. That is reflected in the number of personnel needed for the various categories, and in the levels at which education and training is required. It is also reflected in the degree of dependence on outside education or training facilities.

6. In 1997, Mars Pathfinder began a 10-year programme of robotic exploration of Mars as hundreds of millions of people throughout the world follow the exploits of Sojourner on the surface. Daring spacewalks outside Mir have made this ageing space station once again a working laboratory. The first spacewalk by a Japanese astronaut took place aboard the shuttle Columbia. The heavy-lift Ariane 5 is on target to begin commercial operations in 1998, and the continual launch of communication satellites is bringing instant communications to all parts of the planet. Those few examples of the accomplishments of some of the space agencies around the world illustrate the unique mission that excites and inspires human thought on the planet. And it is that unique mission, the people who carry it out and the laboratories, research centres and launch facilities where the work is accomplished that can make a unique and significant contribution to the educational community.

I. EDUCATION AND TRAINING IN SPACE SCIENCE AND TECHNOLOGY

7. For spacefaring States, education and training in space science and technology consist of production and training of future scientists and engineers for sustainability, and the development of the discipline has been entrenched in the school curriculum from the elementary to the tertiary levels of education. At all levels, education is supported by audio-visual aids of high quality (slides, videotapes, CD-ROM etc). “Enrichment activities” for students, such as visits to planetariums, science fairs and conferences, motivate them to develop an interest in high technology in general and in space science and technology in particular. Many educational institutions in spacefaring States now place emphasis on the importance of an interdisciplinary approach to science and technology and socio-economic education. That approach promotes a strong educational base from elementary through university levels.

8. In developing countries, education and training in space science and technology, where they exist, are often limited in scope. They consist essentially in the demystifying and demythologizing of, and in learning how to apply, the new technologies introduced in this discipline. Some developing countries, such as Brazil, China and India, are spacefaring States that have made significant advances in space science and technology, and their educational curricula have been revolutionized by those advances. Other developing countries are participating actively in space science and technology by contributing experimental payload and hardware, conducting relevant ground-based observations and analysing and interpreting satellite-borne data.

9. The new technologies impinge directly or indirectly on solar-powered devices, on transport and telephone networks, on rural education, on health-care delivery, on new ways of processing goods and on provision of services. Education and training in space science and technology can provide many developing countries with opportunities to modernize and pursue a more dynamic development. Developing countries can take advantage of the benefits of the new space-related technologies within their economic growth and development process.

II. CURRICULA FOR SPACE SCIENCE AND TECHNOLOGY EDUCATION

10. At any given point in the history of humankind, scientists and engineers possess an array of knowledge, skills and practices and a variety of instruments, all of which are built up over time. Over the last 40 years, there has been an accumulation of knowledge and of an enormous corpus of scientific literature on space science and technology. The transmission of that knowledge and information to students via education and training demands that a vibrant curriculum of studies be organized at all levels within the educational systems of different countries. It must be noted, however, that the condition of education (elementary, secondary and tertiary) varies significantly across countries, and across institutions within the same country. Those different conditions lead to differences in the space sciences and technology curricula in terms of course content and modes of presentation.

11. Education and training at the tertiary level, especially at the postgraduate level, often place emphasis on the new developments in space science and technology, the applications of new technologies and the acquisition, processing, interpretation and management of data. The training at the graduate level also requires motivation of students to apply the knowledge acquired in research projects. Students at that level are often of varying intellectual origins and are at different levels of preparedness to engage in a course of study in space science and technology. Remedial measures aimed at filling the gaps in background knowledge are therefore required to ensure that students benefit from the course. Diagnostic tests and exploratory lectures can be given to assess specific areas of inadequacies. What is expected of all the students is cognitive and linguistic capacities, ability for reflective thinking and a general background in science subjects. In programmes in space science and technology, there is always a gap between original ideas that guide the development of the curriculum and the translation of the curriculum into practical terms. That gap varies from country to country, depending on the availability of instructional materials necessary to translate ideas into practice.

12. Four major disciplines are often commonly identified in the education and training programmes of space science and technology at the postgraduate level.* They are briefly discussed below.

A. Remote sensing and Geographic Information Systems

13. A remote sensing applications programme is a particularly important component in space science and technology education. It stresses the fact that remotely sensed data provide an ideal view of the Earth for many studies that require synoptic or periodic observations, such as inventory, surveying and monitoring in agriculture, forestry, range management, geology, water resources and the urban environment. Remote sensing observations make use not only of visible light, but also of several other regions of the electromagnetic spectrum, such as the infrared, thermal and microwave regions. Different techniques may be required to handle and analyse those different types of data. Much of the data is in digital form and can be processed using digital imaging and data analysis techniques to improve the visual appearance or to extract the required information.

14. Such a programme covers the technology of image acquisition, digital image processing, Geographic Information Systems (GIS), ground data collection and use, image interpretation and project planning and management. The programme also includes practical work and offers participants the opportunity to become proficient in the use of image processing and GIS software. Commonly, the first part of the programme is broadly based in order to give participants exposure to different techniques, instrumentation and types of data. A thorough background in the physical principles involved is provided. In the second part of the programme, participants explore different applications of remote sensing and specialize in a specific application to suit their own experience or needs.

B. Satellite communications and information technology

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*For further details, see *Centres for Space Science and Technology Education: Education Curricula* (A/AC.105/649).

15. The satellite communications and information technology programme is suited to develop the skills of university educators, researchers, telecommunication professionals, government personnel and others in the field of satellite communications and its applications to broadcasting, telecommunications, health care, education, disaster management and mitigation, positioning and search and rescue operations. It is designed to assist in the preparation of satellite-based communications projects, policy definition, the establishment of communications systems and the integration of advances in communication technology in day-to-day activities. A major element of the programme consists in ways and means of developing and enhancing public awareness regarding the benefits of satellite-based communications technologies in the improvement of the quality of life.

C. Meteorological satellite applications and global climate change

16. The meteorological satellite applications programme stresses the fact that, while meteorological satellites have operated in space for over three decades, the majority of the scientific, professional and educational communities of the world are still unaware that observations from those satellites are freely accessible, and that they can be applied, directly or combined with other information, to benefit large segments of the population of a country. They can also help to resolve specific problems affecting those populations, especially where the saving of lives, the protection of property or the responsible management of natural resources may be involved.

17. Meteorological satellites have been operating almost continuously since the beginning of the space age. Their continuing presence in space for decades to come is virtually assured, because of the importance that society at large places on the observation and forecasting of weather phenomena. The spacecraft have been launched by various States specifically to meet the needs of professional government meteorologists in those States which are responsible for providing weather forecasts for civil and military interests. However, most weather-satellite-launching States have designed their satellites to operate in such a manner that anyone, anywhere on Earth, who is within radio receiving range of the satellites can acquire the data free and use it for any purpose. Thus, real-time, direct read-out observations from the satellites are being used as an educational or training resource within schools. Such observations can also be used as a tool for forest fire detection, or to support air, sea and land transportation, or agricultural and fishing interests, or for a wide range of other non-meteorological purposes.

18. The global access to meteorological satellite data, as known today, was an initiative of the World Meteorological Organization (WMO); it was conceived to help to ensure that knowledge of space sciences and technologies that evolved as a result of free access to meteorological satellite observations can, and will be, utilized by many more individuals, organizations and States, particularly developing countries. It does so by endowing a core group of specialists in different countries with the analytical skills and technical knowledge that will enable them to instigate and sustain a wide variety of indigenous programmes in which technology supports scientific, economic, educational and humanitarian programmes that will enhance the quality of life for broad segments of the population.

D. Basic space science and atmospheric science

19. With the rapid degradation of the environment, it has become vital for all countries of the world to concentrate on a better understanding of atmospheric dynamics, including the interaction of the atmosphere with the land mass and oceans. Realizing the gravity of the situation, the United Nations Conference on Environment and Development, held at Rio de Janeiro, Brazil, from 3 to 14 June 1992, proposed as part of its Agenda 21, a series of measures for addressing environmental conservation. The developing countries have limited capacity to undertake research and development in the field of basic space science and atmospheric science. The programme does outline basic elements in that field which can be introduced into educational curricula at the postgraduate level.

20. Yet on another level, space technology has made tremendous strides and its impact has been felt in a broad variety of sectors, especially those relating to natural resources and environment, meteorology and communications. Since spacecraft operate in space and receive, as well as transmit, electromagnetic signals through space and the

atmosphere, the development of space technology and consequently its applications can be greatly enhanced through a deeper understanding of basic space science and atmospheric science.*

E. Two examples

21. In all four disciplines (sections A to D above), specific emphasis has to be placed on computer systems for image processing and data analysis. A suggestion of topics organized in appropriate modules is provided in a document issued by the Office for Outer Space Affairs of the Secretariat, entitled “Centres for space science and technology education—education curricula” (A/AC.105/649). The document was prepared specifically for the regional centres for space science and technology education (affiliated to the United Nations); however, the curricula could serve as a guide for any graduate programme in any country in the various disciplines. An improvement to the programme is the addition of a new discipline on microsatellite technology.

22. The South African experience[1] has shown how a mix of traditional systems engineering, project management and technology management could be applied to develop space-related high-technology products at a tertiary institution. The inclusion of a microsatellite technology and perhaps nanosatellite programme in the curricula of space science and technology education in the four disciplines outlined above (A to D) will challenge students with an inclination for engineering to make contributions to space-related hardware development. In an age of “blackboxing” of instruments, such a programme will help to demystify some aspects of instrumentation used to collect and analyse data from space platforms.

III. SPACE SCIENCE AND TECHNOLOGY AND THE NON-SCIENTIFIC COMMUNITY

23. In a report by the Royal Society of London,[2] the importance of conveying scientific and technological concepts and thoughts to the general public was underscored. The committee noted that “Better public understanding of science could be a major element in promoting national prosperity, in raising the public and private decision-making efforts and in enriching the life of the individual. These are nationally important long-term aims and require sustained commitment if they are to be realized. Improving the public understanding of science is an investment in the future not a luxury to be indulged in if and when resources allow.”

24. If there is a need to inform the public on scientific endeavours in general, there is a greater need to encourage public awareness in matters of space science and technology. Although the place of science in human advancement is well recognized by most of the general public, the useful spin-offs of space science and technology are not appreciated as such. It is even more difficult for the public to see the relationship between national prosperity and public understanding of space science and technology. The growing influence of space activities on technology and engineering, on health sciences and the medical profession, on education and on information and communication science is largely unknown to the wider public. To many people, space activities are only directed towards discovering intelligent life in outer space and finding out how weather systems move from one region of the Earth to another.

25. There is therefore an urgent need for an awareness campaign, through existing educational systems, to improve the public understanding of space activities. Such a campaign should produce useful input to public thinking, which will lead to improved decision-making by policy makers on science matters in general, and on space science and technology in particular. Public understanding of the benefits derived from space activities will facilitate release of public and private funds for such activities. More employment will be created and national prosperity will increase.

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*For further details, see UNISPACE III background paper 6 on basic space science and microgravity research and their benefits (A/CONF.184/BP/6).

26. Education and training in space science and technology is therefore not complete without outreach components at the centres for space science and technology education that are being established in different regions of the world at the initiative of the United Nations. Popular summaries of recent space activities, summaries of spin-offs from space science and technology, histories of space launchings with details of success and failures supported by video and film presentations, as well as summaries of social impacts of space activities, are good materials for a purposeful outreach programme. In presenting space science and technology activities to the public in that form, there is a risk of making the activity simply one social activity among others because it has been dissociated from the knowledge and science on which its prominence rests. The risk is worth taking, however, since the section of the public that most needs to be educated, although highly placed in decision-making positions, may not have the science background necessary to appreciate any literature with scientific content. People in such decision-making positions need to be at least familiar with the end products of space science and technology.

IV. REGIONAL CENTRES FOR SPACE SCIENCE AND TECHNOLOGY EDUCATION (AFFILIATED TO THE UNITED NATIONS)

27. As the need to develop indigenous capacity became paramount, the General Assembly, in its resolution 45/72 of 11 December 1990, endorsed the recommendation of its Committee on the Peaceful Uses of Outer Space (COPUOS) that the United Nations should lead, with the active support of its specialized agencies and other international organizations, an international effort to establish regional centres for space science and technology education in existing national/regional educational institutions in the developing countries.

28. The host countries for the centres are: India (for Asia and the Pacific); Brazil and Mexico (for Latin America and the Caribbean); Morocco (for French-speaking countries in Africa); and Nigeria (for English-speaking countries in Africa). Seven central eastern and south-eastern European countries plan to establish a similar centre that will operate in a network mode. There is a plan to establish a similar centre in western Asia.

A. Work programme and model curricula

29. The activities at each centre will be undertaken in two major phases. Phase 1 will emphasize the development and enhancement of the knowledge and skills of university educators and research and applications scientists in both the physical and natural sciences as well as in analytical disciplines. Those activities will be accomplished through rigorous theory, research, applications and field exercises over a nine-month period as laid out in the curricula of the educational programme of each centre. Phase 2 will focus on ensuring that the participants make use of the skills and knowledge gained in phase 1 in their pilot projects.

30. The model curricula for the centres provide for a two- to three-month obligatory common curriculum for all participating scholars, and a six- to seven-month individual curriculum in: (i) remote sensing and geographical information systems; (ii) meteorological satellite applications; (iii) satellite communications and geopositioning systems; and (iv) space and atmospheric sciences. Thereafter, each participating scholar will carry out a 12-month project in his or her own country, where and when the knowledge gained at the centre is put into practical use.

31. In addition to providing opportunities for each scholar to gain the necessary knowledge, research experience and application skills in his or her chosen area of space science and technology, the programme of each centre also requires the scholars to complete an obligatory common assignment, which is the same for all participating scholars and is a prerequisite to the enrolment of each scholar in his or her chosen field of study. The common module will provide all the scholars with an overview of the observation of Earth and its environment from space and the use of data collected in such a process in atmospheric and terrestrial analysis. The obligatory programme will also expose the scholars to the physical principles of remote sensing, satellite orbital characteristics, operational sensors, satellite and ground-based communications, the impact of global positioning satellites on the integration and construction of remote sensing and GIS databases, and the demonstration of selected environmental applications.

32. Each centre aspires to be a highly reputable regional institution, which, as the needs arise, and as directed by its governing board, will grow into a network of specialty and internationally acclaimed affiliate nodes. The centres and their nodes will earn such a badge of honour through their contributions to the development of technologies that are appropriate to the solutions of the problems of their respective regions, and to the advancement of knowledge in an ever-expanding field. The model curricula for the centres provide the benchmark of the academic and performance level necessary to maintain the international standard and character needed for international recognition. Each centre will also foster continuing education programmes for its graduates and awareness programmes for policy and decision makers and the general public in its region.

B. Data management

33. An integral part of each of the centres for space science and technology education is a data management unit. Through such a unit, each centre will have direct linkages with existing relevant global data centres. Such linkages will enable the participating scholars to gain access to and utilize the data in the archives of various databases, particularly when undertaking projects and activities that could benefit from such an access.

C. Participating scholars

34. The possession by each applicant of a sound academic background, experience and an aptitude for engaging in the different activities of the centre cannot be overstressed. The richness of those attributes will have a positive impact on the performance of the applicant at the centre. To that end, each applicant (university educator, research or application scientists) should have obtained, from an internationally recognized university or institution, a minimum of a master’s degree, relevant to his or her chosen field of study, followed by a minimum of five years of relevant practical/working experience. An applicant with a Ph.D. degree, relevant to his or her chosen field of study and from an internationally recognized university or institution, should also have completed a minimum of three years of practical/working experience.

35. Of equal importance is the future of the participating scholars in their own countries on the completion of their studies at the centres. It should be emphasized that the overall mission of the centres is to assist participating countries in developing and enhancing the knowledge and skills of their citizens in relevant aspects of space science and technology in order that such individuals can effectively contribute to national development programmes. In order to ensure that appropriate and rewarding employment opportunities exist for those returning scholars, the sponsoring governments or institutions are obliged to: sponsor development-oriented activities that will gainfully utilize the newly acquired knowledge and skills of the returning scholars; and provide appropriate infrastructure and undertake the requisite preparations and plans for their career on a long-term basis. The sponsoring governments are also obliged to guarantee that a returning scholar would remain in such a position with commensurate and progressive remuneration and other entitlements for a minimum of three to five years.

D. Governing board

36. Because resolution 45/72 specifically limits the role of the United Nations to leading international efforts to establish the centres, it is apparent that once any of the centres is inaugurated, its governing board will assume all decision-making and policy formulation responsibilities for the centre.

37. In the context of the centres, a note is warranted on the purpose of the governing board. A governing board is the overall policy-making body of each centre; it oversees all aspects of the centre. It consists of member States (within the region where the centre is located) that have agreed, through their endorsement of the agreement establishing the centre, to the goals and objectives of the centre, and are committed to work, in cooperation with one another, for the well-being of the centre. A governing board, composed as described above, is necessary for each of the centres because member States and their own citizens are more familiar with their own peculiar needs, aspirations, capabilities and resources and are better equipped to find solutions to local problems that may surface. No part of the United Nations system, including the regional economic commissions, is equipped to address such an array of issues, particularly within the framework of the centres. And because such a centre has evolved through the efforts of the United Nations, the latter, including the relevant regional economic commissions, will serve the centre and its governing board in an advisory capacity.

V. APPRAISAL

38. Education in space science and technology can be introduced at the elementary school level and sustained through the secondary school to the tertiary institution levels. At all levels, space-related topics can be introduced into the general science curriculum. A course in science at those levels should be spread horizontally rather than vertically, placing greater emphasis on a secure foundation than on the levels attained. Such an approach provides the scope for introducing the basic elements of space science.

39. What should pupils learn about space science and technology at the elementary school level and how should the material be delivered? To answer those questions, suggested appropriate topics include popular astronomy, based on what can be seen by the naked eye, and the evidence for such phenomena as gravity. At those levels, pupils are unaware of the underlying theories and the materials should be presented more as story-telling than as a formal scientific presentation. Story-telling, fictional or factual, about space science and technology can be a very powerful early way of conveying notions about the subject.

40. At the high school (secondary school) level, the approach to introducing space science and technology should aim at helping students cultivate the ability to think in terms of science and accounting for what happens in terms of both observable as well as unseen events. Stories told at the elementary school level can be given concrete meaning at that level. The simulation of satellite orbits on personal computers and analysis of simple data from space-based instruments could also be introduced at this level.

41. At the tertiary level, students should be encouraged to develop reflective thinking in their approach to learning about space science and technology. Reflective thinking is the highest in the hierarchy of intellectual skills. It implies that given a problem, a student can analyse the problem, recognize the relevant data to use, recall all the concepts and principal facts relating to the solution of the problem, and, lastly, use all the facts to arrive successfully at the solution.

42. At postgraduate levels, education and training should be more formal. The present areas of education and training in space science and technology, namely, remote sensing, basic space science, satellite meteorology and satellite communication, need to be expanded to cover education and training in the development of microsatellites and nanosatellites. The expanded programme should include outreach programmes.

Notes

[1] A. Schoon Winker and G. W. Milne, "University research and development of a microsatellite", *Research and Development Management*, vol. 17, No. 1 (1997).

[2] Royal Society, *Report of Committee on the Public Understanding of Science* (London, September 1985).

Annex

SPACE SCIENCE AND TECHNOLOGY EDUCATION WITHIN THE SETTING OF SPACE AGENCIES

1. Education and training in space science and technology are integral programmes of the missions of many space organizations both in industrialized and developing countries. For example, such educational programmes exist in CNES, ESA, INPE, ISRO, NASA and NASDA. Each space agency has a unique mission, generally not performed by any other organizational entity within that country. For the purpose of the present background paper, educational programmes in space science and technology are illustrated by the educational elements within NASA.

A. Education

1. Mission, human resources and facilities

2. In the United States, the mission of NASA is as follows:

(a) To advance and communicate scientific knowledge and understanding of Earth, the solar system and the universe and to use the space environment for research;

(b) To explore, use and make possible the development of space for human enterprise;

(c) To conduct research in, develop, verify and transfer advanced aeronautics, space and related technologies.

3. The above-mentioned mission is carried out through four strategic enterprises (space science; Earth science; human exploration and development of space; and aeronautics and space transportation technology) that contribute to five United States national priorities, one of which is educational excellence. Such a unique mission inspires national pride, demonstrates real work applications of the traditional disciplines of science, mathematics, engineering and technology, and generates new knowledge for intellectual consumption.

4. The mission is carried out by people employed by the space agency, institutions of higher education and the private sector. Together, this very talented, highly educated pool of people represent an investment in human capital, many of whom are committed to returning to the educational community knowledge from which they have, as individuals, benefited. Moreover, unique facilities are required by each space agency to carry out its mission. It is the unique national assets, mission, human resources and facilities that provide a venue through which elements of the educational community can learn about and experience the knowledge derived from the mission of the space agency.

5. What is the relationship between those unique assets and the educational community? The NASA strategic Plan 1998, on educational excellence, states: “We involve the education community in our endeavors to inspire America’ s students, create learning opportunities and enlighten inquisitive minds.”* The one guiding word that drives the NASA education programme is “involve”. How NASA involves the educational community in its mission is dependent upon the educational level and both its needs and capabilities.

2. Involving the elementary and secondary education community (kindergarten through grade 12)

*See NASA Policy Directive 1000.1, page 9.

6. The United States elementary and secondary education community is large and diverse. Approximately 51.7 million students are enrolled, taught by approximately 3.1 million teachers, in 14,772 school districts in 50 states and the District of Columbia (Washington, D.C.). Funded at a total of $287.5 billion, over 93 per cent of the amount is provided by the state or locality. Fundamentally, education in the United States is controlled by the individual states and localities, not by the federal Government.

7. Because of such diversity, the NASA education programme at the elementary and secondary level seeks to translate its mission into reality to meet the educational needs of the 50 states. And because of its mission, the primary focus of NASA at the elementary and secondary level is in support of the disciplines of mathematics, science and technology education. Therefore, the programmes are guided by state curriculum standards and frameworks.

8. The NASA education programme (K-12) emanates from the 10 NASA field centres, each of which is assigned specific states, so that in total, all 50 states and the District of Columbia are involved. In applying the knowledge learned from the NASA mission to meet the agenda of education throughout the country, NASA involves the K-12 educational community through five implementation approaches: (a) student support programmes; (b) teacher preparation (pre-service) and enhancement (in-service) programmes; (c) curriculum support and dissemination; (d) educational technology; and (e) support of systemic educational change in a state or locality.

9. In fiscal year 1997, NASA pre-college education programmes involved over 1 million students and 100,000 teachers in all 50 states and the District of Columbia. Although by no means comprehensive, some of the NASA K-12 education activities are described below.

10. *Student support.* Responding to the national need to encourage more under-represented groups to pursue science, mathematics and engineering occupations, NASA annually supports approximately 500 high-school students (grades 10 and 11) to undertake eight-week research apprenticeships at a NASA field centre or university from June to August each year. Each apprentice works with a scientist or engineer to assist in his or her research, thus gaining valuable technical experience. Evaluation results indicate that students participating in the programme enrol as college science and engineering majors in a significantly greater percentage than the general student population.

11. Another example of the K-12 programme targets students in grades six to eight. The programme seeks to provide students and their teachers access to unique NASA instrumentation, data and Earth observations. Using an electronic still camera on board the space shuttle, students use the Internet to send coordinates for an image to the programme operations centre. After review and verifications, coordinates are sent to mission control, which forwards the command to the orbiting space shuttle. On board, a computer directs an internally mounted electronic still camera to capture the image, which is downloaded to mission control and sent back to the student via the Internet. Such Earth observations are integrated into the science and mathematics curriculum by the teacher.

12. *Curriculum support and dissemination.* As previously stated, what students are taught and subsequently learn is determined by local communities and states. Therefore, NASA seeks to understand, in a broad sense, common curricula topics or standards, and engages outside education experts to develop curriculum materials for the life sciences, physical sciences, Earth system science, astronomy and planetology, and mathematics. Those materials are derived from the mission activities conducted through the four NASA enterprises. Materials developed are in print, CD-ROM, Internet-based, or videotape formats. All NASA educational materials are distributed through either an education resource centre (located in each state, usually at a university, museum or similar education venue) or through the Internet via the NASA education home page.

13. *Teacher enhancement.* Support materials developed by NASA serve as the content for most teacher enhancement workshops done by NASA. Such workshops, conducted by previous science, mathematics and technology teachers employed under a NASA contract, are provided to teachers in their schools during the academic term and at NASA field centres during the summer. The NASA Education Workshop, for example, is a programme operated cooperatively with the National Science Teachers Association, the National Council of Teachers of

Mathematics, and the International Technology Educator's Association. The programme, announced nationally, is highly competitive and provides, for 250 K-12 mathematics, science and technology teachers, a two-week in-service experience at a NASA centre. Teachers receive technical briefings on missions and projects, in-depth tours of research and development and operational facilities, and technical training sessions on accessing NASA educational electronic materials and information sources. Significant workshop time is then devoted to applying those experiences to meet the needs of the curriculum or programme of study of the individual teacher.

14. *Education technology*. Perhaps the most significant area of growth in the NASA education programme is the better understanding and use of educational technology in the learning process. An educational technology research and development (R&D) centre has been established at a university to develop state-of-the-art electronic instructional materials and Web-based instruction, and to train teachers in their use. Distance learning programmes, originating from NASA centres, are targeted at teachers on a state, regional and national basis, many times in partnership with United States public television organizations.

15. *Support of systemic change*. As the United States continues to reform science, mathematics and technology instruction in its K-12 schools, NASA has placed emphasis on coordinating the total NASA assets in a given state in order to assist in meeting the educational reform agenda of the state concerned. Largely accomplished by establishing a variety of partnerships, NASA seeks to convene meetings of NASA principal investigators, NASA-trained teachers and commercial contractors with the state educational leadership to determine how those assets may best be utilized within the state.

3. GLOBE programme

16. An opportunity exists for space agencies throughout the world to jointly participate in a programme that integrates numerous approaches as described above. GLOBE is a hands-on, school-based (K-12) international environmental science and education programme. Students in almost 5,000 schools in the United States and over 60 other countries are taking important environmental measurements to produce a global data set of long duration. GLOBE measurements, which have been selected by the world science community, span the environmental study areas of climate, within the field of atmospheric science, and hydrology, soils and land cover, within the field of biology. Students report their data using classroom computers and the World Wide Web and the Internet. The data are archived and also turned into vivid contour maps that are returned to GLOBE schools for use in the classroom.

17. Students in GLOBE schools around the world are performing authentic tasks. The data which they collect are used by scientists in real research to understand the dynamics of the environment of Earth. They are also used by the students themselves to study their local environments and to do research projects with other schools around the world, with electronic mail as their communications mechanism. Such collaboration is enhancing environmental awareness, increasing scientific understanding of Earth and supporting improved student achievement in mathematics and science. At the same time, it is affording students around the world the opportunity to interact meaningfully with one another and thus to glimpses of other cultures.

4. Involving the higher education community

18. The United States higher education system is composed of 14.4 million students and approximately 900,000 faculty members. Funding for higher education totals approximately $192 billion annually, approximately 88 per cent of which is derived from sources other than the Federal Government.

19. Since its beginning in 1958, NASA has involved the higher education community as a significant intellectual resource in carrying out its strategy and missions. In fiscal year 1996, NASA funded 4,860 research grants and contracts at 417 institutions of higher education, totalling approximately $749 million. Research topics carried out

in universities range from astronomy and physics, biological and medical sciences, atmospheric science and oceanography, to aeronautical engineering and materials science.

20. Though by far the largest, research and development actions carried out in higher education institutions represent only one of four implementation approaches used to involve the higher education community in the NASA mission. Additional approaches include student support, faculty enhancement and curriculum support.

21. In fiscal year 1997, NASA higher education programmes involved over 50,000 undergraduate and graduate students and 36,000 community college, college and university faculty members in all 50 states and the District of Columbia. While not comprehensive, some of the NASA higher education programmes are outlined below.

22. *Student support.* Each year NASA supports approximately 400 graduate students seeking to obtain a master's or doctoral degree in a discipline of interest to NASA. That national, competitive programme provides selected students and their professors with a fellowship of $22,000 to conduct research on a topic of interest to the space agency. Students are supported for a three-year period and perform the research in collaboration with a NASA principal investigator.

23. *Curriculum support.* Sometimes a new NASA mission dictates a new type of trained professional to carry out the mission. When Mission to Planet Earth became an approved programme, mission scientists realized that a new type of university graduate would be needed in the future, one who could work towards an understanding of the total Earth as an interrelated system and of the effects of natural and human-induced changes on the global environment. To address that need, the Earth systems science education programme was developed to provide universities with financial support to change undergraduate curricula to support Earth systems science. Approximately 30 universities are currently participating.

24. *Faculty enhancement.* In an effort designed to give new faculty members and others access to and understanding of NASA research needs, each year approximately 300 college and university faculty members are chosen nationally to conduct research at a NASA centre, renewable for one year. Approximately 90 per cent of the 10-week fellowship is devoted to research and 10 per cent to developmental activities. Approximately 40 per cent of the participants in the fellowship programme subsequently receive mainstream NASA R&D funding.

25. *Research and development.* As stated previously, the majority of NASA efforts in higher education are individual R&D grants and contracts. However, there are a few specific programmes that assist in developing research infrastructure and capability. For example, one such programme, the NASA Experimental Programme to Stimulate Competitive Research, provides, on a competitive basis, a $5 million grant to a state to develop a research capability in an area of interest to NASA. States eligible to participate are those that traditionally have not been successful in obtaining significant Federal R&D funding. NASA currently funds 10 such states.

B. Training and development

1. Background

26. To better understand the NASA approach to training and development, some background information is necessary. NASA strongly emphasizes its human resources, giving special priority to recruiting, developing and retaining a high-quality and diverse workforce. Having a capable, highly skilled workforce is critical to NASA success in accomplishing its mission. Currently, as a consequence of budget reductions, the ability of NASA to hire new employees has been and is expected to continue to be rigidly constrained. That in essence means that the achievement of NASA mission results will largely come from the contributions and efforts of the current workforce. Providing the training and development experiences to prepare the current workforce to meet the needs of today and tomorrow is vital.

27. It is also important to understand where organizational responsibility for training and development resides in NASA. Each NASA centre has a training and development office exercising primary responsibility for supporting the training and development needs of the employees and organizations of that centre, as prescribed in NASA policy. Each centre has a specific training budget allocated for that purpose. Since the centres have uniquely defined roles and responsibilities with specifically assigned missions, including designations as centres of excellence, their training needs are different. For instance, Ames Research Center (ARC) supports the Space Science Enterprise in Astrobiology and is a centre of excellence for information technology. ARC has determined the appropriate skill mix that it requires to accomplish those assignments, and its training and development function supports the needs of the ARC workforce. Stennis Space Center, a centre of excellence for rocket propulsion testing, has an entirely different skill mix and different training and development priorities to address.

28. An agency-wide training and development function overlays and supports the different centre training and development functions. At the agency level, two major areas are supported: executive and management training and programme and project management training. Agency-sponsored programmes bring together participants from across the agency to expose them to common approaches and the shared experiences of participants from other centres.

2. Strategic approach to training and development

29. As previously mentioned, NASA utilizes a skill mix assessment process to determine both the current and projected mix of workforce skills required at each NASA installation to achieve desired results. In some cases, to achieve the desired skill mix, personnel relocations are used, or minimal outside hiring occurs. In most cases, training and development is used to address the workforce skill requirements.

30. It is important to ensure that the training and development needs and priorities are aligned with the overall plans, goals and objectives of NASA. The primary objective of the NASA training and development function is to ensure that employees and organizations have the capabilities needed to accomplish NASA missions. That means building a skilled and proficient workforce. Within NASA, required skill sets are vast and diverse, involving scientific, professional, technical and management proficiencies. For example, the Aeronautics and Space Transportation Enterprise has three major technology goals supported by 10 enabling technology objectives. Among the many required technical proficiencies that must be supported are airframe design, aviation systems, flight dynamics and aeropropulsion. To achieve long-range goals, revolutionary technology leaps are anticipated in subsonic transport and aviation safety. It is imperative that NASA investment decisions be aligned to provide the training and development experiences required to adequately prepare the workforce to accomplish those objectives. In fact, within NASA, mere technical proficiency is clearly insufficient. To meet the aggressive goals of the future, NASA must support and develop cutting-edge technical proficiencies.

31. NASA also uses, wherever possible, a competency approach to human resource management and development. Competencies are identified areas of emphasis which describe an ability or a characteristic that has been deemed

essential or critical to job success. For example, senior NASA executives should be competent in leading change, leading people, achieving results, exercising business acumen and building coalitions. To present another example, a manager of large and complex projects should be competent in participating in international partnering arrangements, systems engineering design and presenting information to political leaders and external stakeholders. Determination of job competencies should be based on a sound research and validation programme. Once validated, NASA employs competency assessment and feedback instruments in its training programmes to provide a way to gauge participant competency levels.

3. Four cornerstones

32. The NASA strategic approach to training and development has focused on four components or cornerstones, which support both employee and organization needs. The first two components centre around capability. Capability assumes that the requisite skills (or proficiencies) and competencies are suitably developed and available for application to the specific job. More than half of the NASA workforce is composed of engineers and scientists. Organizationally, NASA is structured around programmes and projects. It is therefore expected that most of the emphasis to date has been on identifying and developing technical skills and competencies, particularly for programme and project managers. The efforts undertaken are known as the Programme/Project Management Initiative (PPMI). The NASA PPMI programme consists of a curriculum of core and skill courses, a professional developmental programme, project management tools and resources, and consultant support to intact project teams. PPMI was established to revitalize the NASA focus on project management competencies. The curriculum itself consists of almost 25 different courses. Additional work has also gone into developing career development maps for future aspiring project managers and other interested personnel that outline recommended formal and informal training and developmental experiences beneficial for growth and advancement. The initiative is called the Project Management Development Process (PMDP). The PMDP process identifies work experiences and training for development of programme and project management knowledge and skills. It is a tool and guide for professional and career planning to prepare for future assignments.

33. Executive and management development is another key priority in skill and competency enhancement. Skills and competencies for senior and mid-level managers and team leaders have been researched and validated. Mid-level managerial competencies, for example, include establishing plans and priorities, monitoring work progress, and resolving work unit conflicts, to name just a few. NASA training programmes and development experiences have been designed to provide learning opportunities to improve skill and competency in those areas. A focus on capability (skills and competencies) alone is not sufficient to achieve mission success. Mission support training is the third necessary component of the NASA training and development initiative. Mission support training involves training in specialty areas and subjects bearing on successful mission accomplishment. They may be subject areas like safety, environmental management, security, or some type of legislatively mandated training. An engine test engineer, for example, in addition to being skilled and competent in propulsion testing techniques and procedures, needs to know, understand and apply other knowledge, skills and abilities, which might involve, for example, safety procedures and practices and environmental control procedures. The mission support component provides NASA employees with other essential training and development experiences required to perform the core function smoothly, properly, safely, efficiently and effectively.

34. Lastly, and perhaps just as importantly, the fourth major component of training and development is professional development. This area addresses individual needs for growth and development. Every individual, although skilled, competent and knowledgeable in performing current responsibilities, has an expectation to grow and learn, and strives to solve new problems and achieve new goals. NASA strongly values individual and professional development, and provides a wide range of avenues to employees to develop their full potential and prepare them for new and different responsibilities.

4. Training and development experiences

35. Both formal and informal training and development methodologies are considered to be essential ingredients in an effective workforce development programme. On-the-job training through selected work experiences constitutes the primary approach for employee development. That may include both NASA and non-NASA work experiences and rotational assignments within the home centre of an employee or to another centre, headquarters, another federal agency or outside the Government entirely. Formal training and educational experiences are used to complement the work experience. Much learning also takes place at technical symposia and conferences. Both undergraduate and graduate tuition assistance programmes are available to NASA employees. Each employee is encouraged to develop an individual development plan in concert with his or her supervisor or manager in order to frame, plan and track his or her individual development needs. The plan should also be aligned with the needs of the organization. The use of mentors, while generally optional, is strongly encouraged. The sound advice of an experienced senior professional can significantly improve the developmental planning process for an employee.

5. Technology and automation

36. Technology and automation advances have brought about new support systems that significantly expand the resources available to employees in performing work assignments. In essence, new learning networks are being created to support job performance. Those networks provide tools, job aides, best practices and other electronic resources, in addition to just-in-time training. The materials are delivered to the employee at his or her workstation, and are available on-line as necessary. For instance, a quality engineer developing calibration requirements for spacecraft design will be able to access NASA calibration policy documents, lexicons, resources, references and World Wide Web links to other organizations such as, in the present example, the repository for national reference standards, the National Institute of Standards and Technology.

37. Other techniques being employed in NASA include the use of groupware and computer conferencing. Groupware is a computer-based technology that supports group and team interaction at the same time and in different places through a networked workstation arrangement. Computer conferencing is being used to establish electronic training classrooms, permitting real-time interaction between trainer and student. The use of distance learning and other alternate delivery techniques and movement to automated tools and resources is expanding rapidly.

C. Training and technology transfer in developing countries

38. Training in the concepts and techniques of remote sensing, geographic information systems, image processing, and geospatial data analysis should be an indispensable part of current technology transfer efforts with developing countries. Effective decision-making regarding environmental issues requires a knowledge of, and facility with, those technologies. However, effective implementation of the technologies also requires that technicians and spatial data analysts understand the context of the task and work with others who are knowledgeable about the environmental disciplines and concepts of geospatial data analysis. Otherwise, the software and systems will become simply a tool for visualization of geospatial data, with little or no meaningful analysis involved.

39. The Earth Resources Observation System (EROS) Data Center of the United States Geological Survey (USGS) has applied the philosophy outlined above in providing training in remote sensing, GIS and image processing in many regions of Africa since 1987. Most USGS/EROS Data Center projects in Africa involve some aspect of training, whether regarding hardware, software and network installation and maintenance, or training in analysis concepts and techniques. Training has been provided in the form of short-term (two to three weeks) and long-term (over one year) in-country courses, formal and informal training and workshops at the EROS Data Center, and coordination of formal training at various institutions of higher learning in the United States.

40. In recent years, USGS has provided training as an important part of two major cooperative projects supported by the United States Agency for International Development (USAID): Sustainable Approaches to Viable Environmental Management, in Madagascar; and the Regional Centre for Training and Applications in Agrometeorology and Operational Hydrology (AGRHYMET), in Niger. Through those efforts, institutions such as

the National Association for the Management of Protected Areas and the National Institute of Geography and Hydrography in Madagascar and the AGRHYMET Centre in Niger have been strengthened in their capacity to integrate multi-source data and to carry out multisectoral geospatial analyses.

41. USGS also provides training to help scientists and information specialists in other countries to make data and information from their countries available through the Internet. The EROS Data Center recently presented the Inter-American Geospatial Data Network (IGDN) Clearinghouse Workshop to a group of scientists and database managers representing government agencies and academic institutions that provide and use geospatial data for the Caribbean region and North, South and Central America. The primary objective of the Workshop was to train participants in the use of Internet-related tools and metadata standards compliant with those of the United States Federal Geographic Data Committee to enable them to establish IGDN nodes in their home countries. The IGDN project promotes the implementation of Internet capabilities throughout the western hemisphere for electronic access to information describing the existence and availability of geospatial data. It is a cooperative project of USAID and USGS and is being supported by the Pan American Institute of Geography and History.