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Open access, virtual science libraries, geospatial analysis and other complementary information and communications technology and science, technology, engineering and mathematics assets to address development issues, with particular attention to education

Report of the Secretary-General

Executive Summary

This report provides an overview of how open access, virtual science libraries, and geographic information systems (GIS) could be harnessed to address development challenges, especially in the area of education. It contains recommendations for consideration by national governments and the international community, with a view to encouraging and expanding further development and adoption of these ICT assets.

Contents

Introduction

1. New information and communication technologies (ICTs) are continuously being developed and older ones improved, but their transformational potential, particularly in science, technology, engineering and mathematics (STEM) education, is not being realized everywhere. In some countries the “digital divide” hinders development efforts, whereas elsewhere, in regions with greater access to ICTs, they are not always used effectively.

2. At its fourteenth session, held in May 2011, the Commission on Science and Technology for Development (CSTD) selected “Open access, virtual science libraries, geospatial analysis and other complementary information and communications technology and science, technology, engineering and mathematics assets to address development issues, with particular attention to education” as one of its priority themes for the 2011–2012 intersessional period.

3. To contribute to a further understanding of this theme and to assist the CSTD in its deliberations at its fifteenth session, the CSTD secretariat convened a panel meeting in Manila, the Philippines, from 13 to 15 December 2011. The present report is based on the findings of the panel, national reports contributed by CSTD members, and other relevant literature.

I. Linking education, development and ICTs

A. Education and development

4. Education at all levels – from primary to tertiary, formal and informal – is widely recognized as an important element of development. Investing in education benefits the individual, society, and the world as a whole. Societal benefits include greater economic competitiveness; an educated and skilled workforce is essential to being competitive in the knowledge-based economy (World Bank, 2011; IICD, 2007: 16–18).

STEM education

5. The need for secondary and tertiary education in STEM fields is particularly important for a variety of reasons. As well as providing a solid basic education and increasing general science and technology literacy, education in STEM subjects can enable developing countries to build up a critical mass of STEM specialists who are the human foundation of innovation in an economy (United Kingdom Science and Learning Expert Group, 2010).

6. STEM education in many developing countries faces a number of problems, including reduced uptake (e.g. decreasing university enrolments), brain-drain and limited focus on local problems. There is a need to make STEM subjects more engaging for students, create demand for skilled people by increasing STEM employment opportunities, incentivize them so that they remain in (or return to) developing countries, and promote better avenues for developing country researchers to access and publish research. The effective use of ICTs and other technologies has a lot to offer in this respect.

B. Role of ICTs in education

7. In their broadest sense, ICTs are a range of technologies that “enable us to receive information and communicate or exchange information with others” (Anderson, 2010: 4). ICTs have the potential to bring significant change to education; to how we learn, how we teach and how we manage our education systems (UNCTAD, 2011; Anderson, 2010: 4).

8. ICTs offer a range of different opportunities for improving knowledge dissemination, educational development and the learning process at all levels. These include expanding access to education to people in remote and disadvantaged communities, transforming the learning environment so that teaching is more relevant for skills needed in the local workplace, enhancing the quality of teaching by supporting the professional development of teachers and improving management systems at all levels (Haddad and Draxler, 2002: 9; Tinio, 2002; Anderson, 2010: 23–28; IICD, 2007: 13).

1. The impact of ICTs on education

9. It has been noted that ICTs can be used to enhance the learning process in three different ways (Tinio, 2002). First, learning about ICTs focuses on the process of learning the science, tools, techniques, etc. behind the technology and how to harness its power. Second, learning with ICTs corresponds to the use of ICTs to improve the learning process in any given subject area. Third, distance learning through ICTs relates to the use of ICTs to allow students to remotely access learning materials and instruction.

2. Appropriate implementation of ICTs

10. At any level, the effective introduction of ICTs in education is not simple or guaranteed. Overhauling existing systems and teaching methods is a significant challenge. Policymakers can do much to help ensure that the introduction of ICTs into education is appropriate, effective and takes into account the realities on the ground (ADB, 2010: 4). Effective educational policies can encourage the successful implementation and use of technology in education. Furthermore, there needs to be a concerted effort to link educational policies with ICT and wider development policies (Haddad and Draxler, 2002: 16; infoDev/World Bank, 2008).

11. Open access, virtual science libraries, and geographic information systems (GIS) are ICT assets that can enhance STEM education and improve accessibility of research findings available, particularly in developing countries. Open access can make journal articles freely available on the Internet and virtual science libraries can be tools for information dissemination and science and technology capacity-building. Furthermore, GIS and geospatial analysis can be used to address local developmental concerns as well as facilitate STEM learning and contribute to the building of an ICT-literate workforce, starting from the earliest levels of education.

II. Sharing the wealth of knowledge: Open access and virtual science libraries

12. In academia, the mainstay of scholarly output is the subscription journal, and the main barrier to dissemination of this academic knowledge is access to published research. This is largely due to journal subscription fees and the location of resources, which can make academic research difficult, time-consuming and costly to find and retrieve. Such challenges affect learners in low-income countries disproportionately, due to limited resources, and therefore contribute to a de facto bias towards strengthening research capabilities in rich countries. Open access and virtual science libraries are two ways in

which ICTs can be harnessed to overcome barriers to the building and dissemination of the global stock of knowledge, particularly in developing countries.

A. Open access

13. The traditional way that research is shared within the academic community is through publication in scholarly journals. Anyone wishing to access material published by the journal is usually required to pay for the privilege, either per article or through a subscription. Over the past two decades, this model has come under increasing criticism from those calling for a more equitable distribution of academic literature to address the barriers faced by those in lower income countries. This alternative model is widely known as "open access".

14. The Budapest Open Access Initiative (BOAI), launched in 2002, defines open access to scholarly literature as: "its free availability on the public internet, permitting any users to read, download, copy, distribute, print, search, or link to the full texts of these articles, crawl them for indexing, pass them as data to software, or use them for any other lawful purpose, without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself….The only constraint on reproduction and distribution, and the only role for copyright in this domain, should be to give authors control over the integrity of their work and the right to be properly acknowledged and cited." (BOAI, cited in Hedlund and Rabow, 2007: 13). There are two distinct forms of open access: gold and green.

15. Gold open access is when the publisher makes the content of a peer-reviewed journal available for free. A list of open access journals can be found on the online Directory of Open Access Journals (DOAJ).[1] It has been estimated that in 2008, 8.5 per cent of all scholarly journal output was in the form of gold open access. Gold open access is further divided into three categories: direct, delayed and hybrid. Direct gold open access is when the whole journal is made publicly available for free. Delayed gold open access is when part of a journal's content, usually the newest, is only available on subscription, whilst the rest, usually the older work, is available for free. Sometimes an author or an author's institution can pay for articles to be made freely accessible – this is known as hybrid gold open access (Laakso *et al.*, 2011: 1–2; Zhong, 2009: 527–528).

16. Green open access involves (self)-archiving of manuscripts, pre-published or published work in alternative storage locations, either virtual or physical, including: uploading them to a personal webpage, placing them in an institutional repository or placing them in a subject-focused repository. An estimated 11.9 per cent of all scholarly articles published in 2008 were available through green open access.[2] Journal articles in these storage locations can be searched for using search engines such as Google Scholar (Laakso *et al.* 2011: 1–2; Zhong, 2009: 527–528).

1. Potential of open access

17. Open access offers many benefits for researchers. For individuals and institutions, it can lead to increased visibility and presence on the Internet. It is likely that the reach of research undertaken at the institution will be greater and it provides a resource bank that

[1] See http://www.doaj.org/.

[2] For an extensive list of Open Access Repositories, see the Directory of Open Access Repositories (OpenDOAR) at http://www.opendoar.org/, the Registry of Open Access Repositories (ROAR) at http://roar.eprints.org/ and the Ranking Web of World Repositories at http://repositories.webometrics.info/toprep.asp?offset=50.

can help the institution manage and evaluate their research activities more efficiently. In this sense, it can be an important marketing tool for the institution (RCAAP, 2009: 7).

18. Developing countries can benefit immensely from open access as it offers alternative gateways to and outlets for research. In their study of open access in Asia, Das *et al.* (2008: 1–2) noted the rise of open access channels in a plethora of different forms: digital libraries, open access journals, institutional repositories, national-level repositories, open courseware, data indexing services, etc.[3] Importantly, they found that most open access initiatives are supported by Government bodies, public institutions or non-profit organizations (NRC, 2006: 87–88).

19. Appreciation of the benefits of open access has supported the growth of the movement. Since the BOAI in 2002, there have been many initiatives to encourage and promote open access. Open access publishing continues to grow in stature (Greyson *et al.*, 2010; Zhong, 2009: 527–528).[4] Box 1 shows a list of major open access statements. By 2010, there were 1,764 institutional and subject archives or repositories listed in the Registry of Open Access Repositories, whose contents are searchable through Google (Moore, 2010). The United Nations has been a vocal supporter of open access, and a number of United Nations entities have been involved in promoting and facilitating better access to research, particularly for scholars in developing countries (UNESCO, 2011c; FAO, 2011; WHO, 2011; WIPO, 2011).

Box 1. Major open access statements

- Budapest Open Access Initiative Statement, 2001
- Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities, 2003
- Bethesda Statement on Open Access, 2003
- World Summit on the Information Society (WSIS) Declaration of Principles and Plan of Action, 2003
- International Federation of Library Associations and Institutions (IFLA) Statement on Open Access to Scholarly Literature and Research Documentation, 2004
- Washington DC Principles for Free Access to Science: A Statement from Not-for-Profit Publishers, 2004
- Australian Research Information Infrastructure Committee (ARIIC) Open Access Statement, 2005
- Salvador Declaration on Open Access: The Developing World Perspective, 2005
- Bangalore Declaration on National Open Access Policy for Developing Countries, 2006
- European Research Consortium for Informatics and Mathematics (ERCIM) Statement on Open Access, 2006
- Indian National Knowledge Commission (NKC) Statements on Open Access, 2007

[3] According to the Working Group on Broadband and Science Final Report of the Broadband Commission for Digital Development, open access has the potential to help the global South become '…more than just information consumers' (www.broadbandcommission.org).

[4] To see a list of major open access statements over the past decade, see Das et al. (2008: 3).

- OECD Declaration on Access to Research Data from Public Funding, 2007
- Welcome Trust Position Statement in support of open and unrestricted access to published research, 2007.

Source: Das et al., 2008: 3.

2. Barriers to broader levels of open access

20. Despite growing support for open access and widespread appreciation of the potential benefits it can provide, several barriers to its development deserve attention.

21. First, with respect to content, English is the main language of communication of research and of many of the repositories that house it. Limited use of local languages can hinder researchers from developing countries from utilizing research and having an outlet for their own research. This is what has been termed the "content divide" (Tinio, 2002). Second, despite the perceived potential of open access, its impact is not easy to measure and specific indicators are difficult to obtain. Current evaluations appear rather limited, although this seems to be improving as the number and scope of impact studies increase.[5] Third, there are issues concerning publishing standards and rules. Understandably, many publishers are resistant to open access as it requires a complete change in their business model. A lot of publishers have undertaken this challenge, and variations on the green and gold models are increasingly common. However, the legality of archiving work that has been published in a journal is not always clear, leading authors to worry about plagiarism and who has publishing rights over their work. The open access movement challenges the traditional incentive structures faced by researchers and institutions. In order to maintain or improve personal and institutional reputation, academics aim to publish in journals that have the highest rank in terms of impact, most of which are not open access. However, the growing use and importance of open access journals does appear to be increasing pressure on ranking institutions to find alternative ways to assess impact (Chan *et al.*, 2011). Fourth, there are concerns over how to fund the publication (online or otherwise) of journals. Existing practices – such as allocating portions of research grants to journal administration costs, or getting authors or their institutions to pay for the privilege of being published – have given rise to debate about their impact on the financial sustainability of journals, preservation of knowledge, and scholarly publication in general. And finally, contextual constraints like access to enabling infrastructure (e.g. ICTs, electricity) must be in place to exploit the benefits of open access.

B. Virtual science libraries

22. The use of virtual spaces in which information can be stored, searched for and shared has become increasingly important as ICTs have brought about opportunities for easier access to the global stock of knowledge. Over the past decade, a lot of time, energy and financing have been invested into the development of virtual libraries, and in particular virtual science libraries, where information is complex and journals tend to be more expensive.

23. Virtual library is "a library that exists, without any regard to a physical space or location". (Riccio, 2001). Virtual libraries can house content themselves, or they can act as a portal to distributed online content housed in other online repositories, such as digital or

[5] For a bibliography of impact studies, see Hitchcock, 2011.

electronic content of libraries. In this sense, a virtual library provides remote access to the content and services of libraries and other information resources.

24. Virtual science libraries come in a range of different shapes and sizes. Although their online nature leaves them without borders, many virtual science libraries are national endeavours. For example, the Guyana Health Library is specifically geared towards enhancing access to health information in Guyana (Pan-American Health Organization, 2011).[6] The Bangladesh National Scientific and Technical Documentation Centre (BANSDOC) has an online facility to provide access to citizens to its library online.[7] Other virtual science libraries are the product of collaborative efforts across borders, such as the CRDF Virtual Science Library Program connecting countries such as Iraq, Morocco, Algeria, Tunisia, Armenia and Afghanistan.[8]

25. Virtual science library access restrictions vary, and are often related to user affiliations. In some cases, users from developing countries are given less restricted, and possibly free, access. This is the case with the US National Bureau of Economic Research (NBER), where full-text downloads of NBER Working Papers are free for residents of developing countries (NBER, 2011). Yale University's Library provides links to programs that offer developing countries free or low-cost access to high quality, peer-reviewed scientific journals. Many other international organizations are making big efforts in this area.

Box 2. Iraqi Virtual Science Library

As with many developing countries, in Iraq, access to high quality research publications was limited and the scientific research community suffered from being stuck in a "de facto intellectual ghetto" (Bibliotheca Alexandrina, 2011). To overcome this problem, in 2007, the United States Civilian Research and Development Foundation (CRDF) set up the Iraqi Virtual Science Library and subsequently handed over responsibility for the library to the Government of Iraq in 2010. In order for the library to be a success, it had to address three key challenges: determining appropriate content for open access, ensuring the library is easy to use and making sure the library is sustainable. To date, over 25 universities and research institutions, covering over 8,000 individual users, have accessed the system. More than 1 million journal articles have been downloaded and Iraq's research publication rate has tripled.

Source: Bibliotheca Alexandrina (2011); University of Maryland (2011); Thomson Reuters (2006); CRDF Global (2011); European Commission (2006)

Potential of virtual science libraries

26. Virtual science libraries offer many advantages. Search capabilities can be enhanced due to content being in a digital format: old print-based content which is digitized becomes accessible while new stocks of Internet-only content are generated and opened up. Materials are available for download regardless of location, which can allow knowledge to be disseminated more widely. Furthermore, the potential exists for multiple, concurrent users. Box 2 gives details of the Iraqi virtual science library, which, through collaboration with a range of publishing companies, offers the Iraqi scientific research community access to many academic journals.

[6] http://www.guy.paho.org/VHL.pdf.
[7] http://www.bansdoc.gov.bd/.
[8] http://maghrebvsl.org/crdf/.

27. Lack of Internet connectivity is often a barrier to taking advantage of web-based ICT applications for Virtual Science Libraries. One way in which these connectivity issues may be overcome is through government-funded national level networks that interconnect local networks of research and higher education institutions in the country. National Research and Education Networking organizations have been established around the world to undertake this task (see Box 3) (Dyer, 2009).

Box 3. Examples of National Research and Education Networks (NRENs)

Pakistan Education and Research Network
Implemented in 2002, the Pakistan Education and Research Network (PERN) is connected with 60 public sector universities via a fibre-optic broadband network. A digital library service provides free access for all universities to over 23,000 research journals and 45,000 graduate-level books. PERN has integrated Pakistani scientists and researchers and encouraged national knowledge networks on 155 Mbps connectivity. PERN2 was launched in 2008 with an increased bandwidth of 10 Gbps. It connects PERN with foreign research and education networks such as the one in Nepal.

Nepal Research and Education Network
The Nepal Research and Education Network (NREN) is a public–private initiative established in 2007 to reverse brain drain and develop research infrastructure. It is using ICTs to create a national network for advanced research and education that will also give researchers access to information and data around the world. In 2008, NREN obtained a grant from the Information Society Innovation Fund in Asia for a project to develop the NREN's high-speed backbone. This network is developing e-learning for higher education in villages and remote areas in the local language and creating an Intranet portal and telemedicine for health posts in villages. NREN collaborates with counterparts in South Asia and elsewhere. NREN's activities are supported by the Network Start-up Resource Center at the University of Oregon in the USA and by Keio University in Japan, among others.

Source: (UNESCO, 2010).

C. Connecting "openness"

28. Open access initiatives and the development of virtual science libraries are part of a wider movement towards greater openness. Open standards and open source are two other issues which have been the subject of much international discussion.[9] There are in particular many parallels between the more recent open access movement and the development of the open source movement (Moody, 2006). Consequently, a support strategy for open access may use similar mechanisms as those for open source and open standards (Kelly *et al.*, 2007: 172).

29. It has been argued that greater openness can help to lower costs, improve accessibility, and advance prospects for long-term preservation of scholarly works (Corrado, 2005). However, a number of issues need to be addressed. First, openness can be interpreted differently, for instance it can be taken to mean free to use, free to modify, etc.

[9] Broadly speaking, open standards allow products developed by different companies to be interoperable – i.e. compatible with each other – and to be interchangeable. Open source software gives users the right to freely access the source code of the software in order to study it, change it and redistribute it without restriction (Cerri and Fuggetta, 2007: 1–2).

(Cerri and Fuggetta, 2007). Second, connected to this, concerns exist around the protection of intellectual property rights. Third, demands for openness bring with them concerns over security, authenticity and accuracy. Fourth, there are concerns with respect to the preservation of knowledge. It is not clear which stakeholder(s) will archive digital journals for how long or which standards will be compatible with upgraded systems.

30. A debate continues over the extent to which access to source code will make software more susceptible to hacking (Viega, 2004; Wheeler, 2011). Whilst resources such as Wikipedia have opened up access to multilingual, current information, the user-generated content of these resources is not formally peer-reviewed and subject to considerable accuracy concerns.

31. The process of achieving greater openness is affected by conflict and trade-offs. Policies that aim to achieve greater openness must balance commercial interests, intellectual property rights and social goals such as greater dissemination of knowledge. International dialogue is important in this regard.

III. Geographic information systems and geospatial analysis to enhance education

32. Geographic information systems (GIS) are information systems that allow users to track, store, edit, and analyse geographic information. Geospatial analysis is the application of statistical analysis and other analytical techniques to geographically based data, including GIS data. It is the process of turning raw geographical data into useful information.

33. Arising in the 1960s from the nexus between the emerging fields of computer cartography, spatial statistics and analysis, and computer science, GIS initially focused on algorithm development and map production. As computing power developed, GIS became more widely available and it began to have an impact in a variety of disciplines. As such, it became apparent that GIS would have significant, long-term impacts on society and on the policymaking process. By the 1980s and early 1990s, Governments, businesses and other organizations were integrating GIS into their activities in order to address a range of complex natural, social and infrastructure issues (Nyerges *et al.,* 2011: 4).

A. Geographic information systems and geospatial analysis

34. GIS can keep track not only of events, activities, objects or phenomena, but also where and how they occur, i.e. information of a geographical nature (Longley *et al.*, 2005: 4). GIS databases are generated from information collected at the physical location and by remote sensing. Information collected at the physical location includes topographical data obtained using direct surveying techniques and observational notes about certain attributes captured using photographs or written notes. This is combined with coordinate data from global positioning satellites (GPS).

35. Remote sensing is the technique of obtaining information about objects on the Earth’s surface without physically coming into contact with them. Remote sensing data is generated using sensors – such as cameras, scanners, radiometers and radars – that are mounted on aircraft and satellites. These are located at considerable heights from the surface of the Earth and they store data as images on photographic films and videotapes or in a digital format.

Using GIS for geospatial analysis and mapping

36. Beyond the storage of complex geographical information, GIS and its associated software is extremely useful because of the analysis and modelling techniques it provides. GIS offers various ways to organize and analyse geographical information in order to structure and solve problems, functions that have become increasingly important in today's complex and interdependent world.

37. Geospatial analysis involves applying transformations, manipulations and methods to basic geographical information in order to reveal patterns and anomalies that are not immediately obvious. Essentially, geospatial analysis is the process by which raw geographical data is turned into useful information: through geospatial transformations, the analyst aims to reveal things that might not otherwise have been seen (Longley *et al.*, 2005: 316; De Smith *et al.*, 2010: 23; Heywood *et al.*, 2006: 18).

38. GIS data and the outputs from geospatial analysis are commonly represented in the form of a detailed, multi-layered map. By superimposing different layers of spatial data upon each other, relative information about a single point can be brought together (Rubenstein and Roy, 2011). Data about a single point can be visually represented on a map.

39. The human element of using GIS and undertaking geospatial analysis is essential. The collection and analysis of geographic data involves decisions about which details should be captured and how problems should be framed, and the implications of these choices should be taken into account when making use of geospatial analysis, particularly during policy making (Longley *et al.*, 2006: 65–70, 316–318).

40. GIS and geospatial analysis have a wide range of uses in many fields and an estimated $50 billion–$60 billion is spent annually on collecting, analysing and maintaining geospatial data (Gibson, 2011). Some of the practical applications of GIS are in table 1.

Table 1.
Practical applications of GIS

GIS application	*Examples*
Disaster risk management	Calculation of emergency response times and the movement of response resources (for logistics) in the case of a natural disaster
Indicators	Population and demographic studies; poverty mapping
Resource management	Natural resource mapping, such as finding wetlands that need protection strategies regarding pollution; environmental impact-assessment
Commercial/business planning	New business location decisions based on consumer trends or identification of an underserved market; asset management and location planning; marketing
Urban planning	Transport system planning; infrastructure assessment and development
Disease surveillance	Disease surveillance to inform pandemic

GIS application	*Examples*
	planning and enhance preparedness
Military	Security, intelligence and counter-terrorism; criminology; military planning

Source: Longley et al. (2005: 41–42); ESRI (2011a).

B. Using GIS and geospatial analysis to enhance education

41. GIS and geospatial analysis as a set of ICT and STEM tools and techniques can enhance education, particularly starting at the earliest levels of education where youth can develop spatial and analytic abilities and discern the relevance of GIS for addressing local development concerns. There are two ways to think about how education and GIS interact: learning about GIS and learning through GIS. Learning about GIS is related to the need for education programmes that train people to become GIS practitioners. The growing importance of GIS as a tool in all parts of the economy underscores the need to develop a GIS-literate workforce.

42. Learning through GIS corresponds to using it as an educational tool to offer additional ways to develop important spatial abilities. By expressing relationships within spatial structures (such as maps and computer-aided design drawings), it is possible to perceive, remember and analyse the properties of objects and the relationships between them.

43. GIS and geospatial analysis can also assist students in developing essential skills in data analysis and manipulation such as exporting data in different formats to spreadsheets and presenting data to classmates. These abilities are particularly important in STEM subjects and associated careers (NRC, 2005: 3–5; Kerski, 2008; Clements, 2004: 267).

44. Broadly speaking, there are two major spatial abilities: spatial orientation and spatial visualization. Spatial orientation relates to knowing where one is and how to get around in that space. This ability is important from an early age and is needed to navigate everyday life. Routine questions related to spatial orientation focus on location (e.g. where is the nearest hospital?), patterns (e.g. how is a disease spreading?), trends (e.g. where are there increasing levels of soil erosion?), conditions (e.g. where can I find a water pump within 1km of my house?) and implications (e.g. if we build this road, what will be the effect on traffic flow in the city?).

Box 4. *Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum*

One of the most in-depth investigations into the relevance of integrating GIS into education was undertaken by the United States National Research Council. During its study, it determined that new ICT tools and techniques such as those offered by GIS and geospatial analysis do have the potential to enhance education in nearly all subjects. It notes that spatial thinking is important in art and design, psychology, biology, chemistry, physics, mathematics, social sciences and computing sciences. Spatial thinking also has enormous potential in terms of understanding and appreciating inter-disciplinarity. However, the study emphasized the need to understand why and in what context these technologies should be implemented if they are to be used effectively.

Some of the recommendations set out in their report, entitled *Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum*, included:

- Need for coordinated approach to integrating GIS in education, bringing together GIS designers, psychologists and educators;
- Development of a grassroots-level group to coordinate the development of GIS software, based on feedback from users;
- Training programmes and curriculum guidelines should be established, and GIS educators and representatives of educational establishments should be involved in this process; and
- More research should be undertaken on the extent to which GIS improves academic achievement.

Source: United States National Research Council (2005).

45. Spatial visualization, on the other hand, is useful for understanding complex issues, such as many scientific, mathematical and engineering problems, and associated tools and techniques. If one can visualize the problem, it can help to understand it better. For instance, research on the DNA double-helix was significantly helped by spatial visualization, and it continues to be important in biochemistry in the visualization of three-dimensional spatial arrangements of enzymes to explore interactions, which can lead to new understandings in biochemistry and drug development (Clements, 2004: 267; Heywood, *et al.*, 2006: 3; NRC, 2005: 1–5).

46. Just because spatial thinking is important does not mean it develops to a high degree automatically and universally. One of the best ways to cultivate spatial thinking and spatial analysis is by learning through GIS as it involves exploring the spatial characteristics of events, activities, objects or phenomena that are not obvious to the naked eye (see Box 4 and Liben, 2006: 238; Kerski, 2008).

47. Learning about GIS and learning through GIS can take place in formal or informal settings and can be aimed at school pupils, university students, policymakers and others. The development of training programmes focused on learning about GIS has been growing, and in universities it is becoming more widespread, either as a module or as a fully-fledged course.

48. An increasing number of countries are beginning to develop programmes that utilize the power of GIS to enhance education, particularly STEM education, and especially at the secondary level. An example of an initiative to learn through GIS is the case of geography teaching at the tertiary level in South Africa. In particular, the use of local data and allowing students to analyse issues close to home has helped immensely to leverage the power of GIS to enhance learning (Innes, 2011).

49. In order to help teachers integrate GIS in the classroom in Turkey, in 2008, *The GIS for Teachers* book was published. Accompanying the book was a DVD and a one-year licence version of the GIS software package, ArcView 9.2, as well as data, handouts and exams in PDF format. Furthermore, a webpage was set up and a brochure was distributed informing people about the book and where to access it. The book received good feedback from academics, teachers and civil servants working different public sectors, and within a year 700 books had been purchased (Demirci and Karaburun, 2009). Box 5 gives an overview of initiatives to integrate GIS into education in Europe.

Box 5. GIS in European education

In 2009, i-Guess undertook a study of selected countries in Europe in order to assess the extent to which GIS was being implemented in schools and what the impacts were. The countries involved in the study were Austria, Belgium, Bulgaria, Finland, France, Greece, Hungary and England.

The report found that GIS was utilized in a wide range of different subjects within both social and economic sciences and natural and environmental sciences. Study topics in which GIS was utilized included crime, landscape management, retail analysis and environmental modelling. In qualitative terms, the study found that GIS technology was extremely useful in helping students explore their world and handle and display spatial information.

Across countries, the report found that teaching styles differed, and any GIS programme should appreciate this. Also, country needs were different and so promotion should take this into account. The report noted a number of challenges that policymakers could address. This included promoting professional development for teachers in the area of GIS, and also setting use and implementation standards for the technology.

Source: i-Guess/EC (2009).

Barriers to GIS in education

50. Despite the increasing attempts to integrate GIS into education, it still remains a challenge. First, human capacity in the field of GIS, in terms of teaching and using it as a development tool and utilizing it as a teaching tool, is limited. Lack of personnel with appropriate skills and training is a considerable problem (Stuart *et al.*, 2009). With regards to learning about GIS, most capacity–building efforts often focus on data production, not usage and application of GIS, or education. Learning through GIS appears difficult to institutionalize: teachers themselves need to know the technology as well as understand and to be willing to implement alternative teaching methods that utilize the technology. Second, costs – upfront costs of hardware, software and services (such as customization), and ongoing costs of training, maintenance and data – have been cited as a barrier. Some costs have been lowered as open source GIS software has become available and GIS applications have been designed to utilize the power of modern GPS-enabled mobile phones. However, the large amounts of complex data needed to build up detailed GIS layers is very expensive, particularly if high resolution data is required. Maintaining up-to-date information is an ongoing cost and often accounts for 70 per cent of total GIS costs. Third, lack of support from decision-makers is often related to their limited awareness of the potential usefulness of GIS. At an organizational level, GIS practitioners have often found it difficult to explain to administrators its value as a tool for improving critical thinking and improving issues pertinent to the organization. Increasing pressure in many organizations and government departments to reduce budgetary spending mean getting GIS on the agenda is made all the more difficult (Stuart *et al.*, 2009; ArcUser Online, 2011). Fourth, erratic electricity supply and poor communication infrastructure could seriously hinder GIS applications. The complex array of technologies involved in using GIS requires electrical power. The Internet and mobile telecommunication systems are integral to GIS, such as GPS and remote sensing. Where connections will come from and how they will be paid for is a critical issue (Farah, 2011).

C. Integrating GIS and spatial thinking into education – Policy options to overcome these barriers need to address all dimensions of GIS usage

1. Build human capacity at all levels to deliver GIS in education

51. Steps to improve spatial thinking in the education system through the use of GIS need to be supported by strong education policies. Education policy related to GIS must be targeted towards training teachers to teach GIS and teach through GIS, and getting more students to study GIS and embrace GIS as a learning tool. To generate public knowledge about and support for GIS, community-based GIS activities can be organized. This can generate significant local data, as well increasing awareness of the technology and its application (Nyerges *et al.*, 2011: 4).

52. Support for GIS amongst policy makers is necessary, particularly considering the potential of GIS to support evidence-based policy making. Training in GIS for policy makers can help to raise awareness, demonstrating the positive impact GIS can have in education, both as a learning tool and as a subject area.

2. Evaluating the impacts of GIS education

53. There is need for a greater understanding of the impacts of GIS in education. The limited research so far means that, as with the use of ICTs in education more widely, there are still question marks over when and where is it most effective, and how and at what cost should it be implemented. Governments may wish to commission in-depth studies to answer some of these concerns.

3. Coordination of GIS data

54. Geospatial data is complex, large in size and often extremely expensive. Duplication of data creation and maintenance is a considerable waste of resources, but can be fixed if there is good coordination between GIS users within different government departments. Setting up a government body dedicated to obtaining, storing and disseminating geographic data, including remote-sensing data, is one way of making GIS data available for public use at the lowest cost. Central data repositories for geospatial data can be set up and managed by designated organizations. This was the approach taken by the United States state of Pennsylvania, where the state Government identified a number of “data stewards” to create and maintain data and manage an online data clearinghouse (Shanley, 2007: 17).

4. Building networks and undertaking collaborations

55. Capacity–building in GIS and geospatial analysis would be significantly enhanced by wider education networks and partnerships to improve training schemes and ensure the sharing of best practices. Multilateral networks can allow participants to connect with multiple institutions and prioritize those interactions that are of greatest benefit the particular needs of their countries (Kifuonyi, 2009). An example of this type of network is the recently established United Nations Initiative on Global Geospatial Information Management (GGIM). Although still in its infancy, the GGIM provides a forum to improve coordination among Member States and international organizations on the management of global geospatial information. Stakeholders have the opportunity to discuss developments in geospatial technology and consider ways to engage in cooperative activities with the private sector to address cross-cutting development issues (GGIM, 2011).

56. GIS and geospatial analysis, open access, virtual science libraries are emerging ICT assets which have the potential to enhance STEM education. Integrating these ICT assets into education will require human capacity, educational framework conditions and policies,

technological and basic infrastructure, as well as partnerships (North–South and South–South) for effective collaboration.

IV. Findings and suggestions

57. This concluding section summarizes the findings presented above and proposes a set of key issues for consideration by the Commission on Science and Technology for Development.

A. Findings

(a) Open access and virtual science libraries are two complementary mechanisms to increase and extend knowledge flows. They contribute to overcoming some limitations associated with obtaining data and research;

(b) GIS and geospatial analysis are used in many sectors of society and have important applications in addressing development challenges. Meanwhile, GIS can also be used in education to help develop spatial abilities required in a range of different subjects beyond geography;

(c) Learning through GIS is not widespread and the transformational potential of GIS in education remains untapped;

(d) The effective introduction of ICTs in the learning process requires not only technology but also human capacity, educational framework conditions, infrastructure and national policies.

B. Suggestions

(a) Governments, in partnerships with other stakeholders, should seek to overcome basic infrastructural constraints (e.g. ICTs, electricity and other basic needs) which prohibit access to and use of these ICT assets;

(b) Policymakers should collaborate to address the “content divide” by exploring ways of increasing publication and accessibility of content in multiple languages.

1. Open Access

(a) Policymakers could encourage national research agencies and foundations to include open access in their funding mandates whereby publicly-funded research is made freely accessible;

(b) Policymakers should ensure that public data and research, including raw data from publicly funded experiments, studies or investigations, is available for free and in an openly accessible format;

(c) Governments and the international community should encourage international collaboration in digitizing publicly-funded research, making it available online for free and ensuring it is easy to find.

2. Virtual Science Libraries

(a) Governments, in partnership with other stakeholders, should ensure the logistical and financial viability of virtual science libraries;

(b) Governments should encourage the formation of national research and education networking (NREN) organizations, with local champions and high visibility, separating network ownership and service provision and ensuring that financial sustainability is achieved from the start.

3. GIS

(a) Schools should improve spatial thinking in the education system through GIS by adopting strong education policies including the integration of GIS or fundamental concepts of geography that lead to spatial thinking in national curricula and by supporting teacher training to include spatial thinking and GIS;

(b) Government bodies should be established dedicated to obtaining, storing and disseminating geographic data, including remote-sensing data, to make GIS data available for public use at the lowest cost;

(c) Support for GIS amongst policymakers is necessary, particularly considering the potential of GIS to support evidence-based policy making. International collaboration between education institutes can facilitate training in GIS for policymakers to help raise awareness of the technology and build capacity;

(d) Policymakers can encourage the private sector to be involved in the process of increasing technology openness for geo-spatial data. For example, public sector organizations (e.g., government agencies, libraries) can collaborate with private sector firms to index geospatial information and make it easily searchable and available online.

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