# Measuring the Global Research Environment: Information Science Challenges for the 21st Century


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**"What does the global research environment look like?" This paper presents a summary look at the results of efforts to address this question using available indicators on global research production. It was surprising how little information is available, how difficult some of it is to access and how flawed the data are. The three most useful data sources were UNESCO (United Nations Educational, Scientific and Cultural Organization) Research and Development data (1996-2002), the Institute of Scientific Information publications listings for January 1998 through March 2003, and the World of Learning 2002 reference volume. The data showed that it is difficult to easily get a good overview of the global research situation from existing sources. Furthermore, inequalities between countries in research capacity are marked and challenging. Information science offers strategies for responding to both of these challenges. In both cases improvements are likely if access to information can be facilitated and the process of integrating information from different sources can be simplified, allowing transformation into effective action. The global research environment thus serves as a case study for the focus of this paper – the exploration of information science responses to challenges in the management, exchange and implementation of knowledge globally.**

## Introduction

In a February 2004 editorial in Science, United Nations Secretary-General, Kofi Annan, asserted that “no nation that wants to shape informed policies and take effective action on such issues [as stimulating growth, preventing global and environmental damage, introducing new technologies, thwarting terrorism, and responding quickly to the spread of new disease] can afford to be without its own independent capacity in science and technology.” He called for increased global cooperation in developing a “large collective reservoir of knowledge and expertise” that will benefit all nations and increase the capacity of developing countries to successfully manage their own destinies. (Annan, 2004)

Kofi Annan’s editorial generates questions about what the world situation is actually like when it comes to “knowledge and expertise” and its management, exchange and implementation. These issues are central to the concerns of the field of information science & technology. There are many factors that contribute to a full understanding of how knowledge and expertise are currently being exchanged and utilized around the globe. Assessing global research production is one key measure, and this paper presents the results of efforts to get a sense of the global research environment using available indicators on global research production.

The global research environment was chosen as the starting point for two reasons. First it was assumed (mistakenly, as it turned out) that data would be readily available and that this task could be conducted quickly, allowing other, more difficult, issues to be tackled subsequently. Second, a sense of the global research environment was useful contextual information for the development of the new field of Integration and Implementation Sciences (Bammer, 2005, & http://www.anu.edu.au/iisn). The intention is to build this new specialization in parallel in developed and developing countries, so that an awareness of global capacity is central. In brief, Integration and Implementation Sciences aims to improve the theory and methods needed for cross-disciplinary research tackling complex problems and the use of that research in informing effective policy and action. It combines information sciences with systems thinking, participatory methods, and a deeper understanding of how research influences policy, practice and product. For all countries to effectively tackle the problems they face, they need an effective research base and an enhanced understanding of how to convert research to effective action.

The results of the investigation have two dimensions. First are the challenges of gathering, integrating and presenting data. Second are the inequalities in research capacity evident in the results. Both are relevant to information scientists. The global research environment thus serves as a case study for the focus of this paper – the exploration of information science responses to challenges in the management, exchange and implementation of knowledge globally.

Overall it was surprising how little information is available, how difficult some of it is to access and how flawed the data are. As well as demonstrating a need for improved statistical collections, this speaks to a need for better systems for identifying, locating and retrieving the authoritative and diverse information necessary for addressing complex issues. The value of any “reservoir of knowledge and expertise” will depend on the strength of these systems. Potential responses to the need for better systems include greater standardization in data collection, more effective concept/data-mapping tools in practical topics where diverse traditional domains intersect, and new ways of simplifying the presentation of multi-dimensional information for rapid comprehension, and flexible application and implementation. Regarding the issue of independent capacity, the data show clear deficiencies in the research production and capacity of developing countries, which highlights the need for exploration into the information needs of those countries and how to better facilitate the management, exchange and implementation of knowledge there.

There are exciting and interesting opportunities in contemplating information science strategies for application to these complex and multi-dimensional information issues. Many of these strategies can be described as either improving access to information or simplifying the process of integrating information from diverse sources into local systems where it can be utilized to generate practical action.

The promotion of established standards for data sharing and collection access, like the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) or the OpenURL standard, may be helpful in making more information “findable” by automated systems. The application of RSS (Rich Site Summary or Really Simple Syndication) would rapidly put more relevant information in the hands of those who need it and free more time for actual problem-solving. These types of “access” strategies would enable easier aggregation of global research data and also would make it easier for developing nations to locate the knowledge relevant to them.

The provision of data compatible with the XML (eXtensible Markup Language) standard would enable the integration of external data into local systems with much less labor. Additionally, innovative applications of ontologies and taxonomies and creative information visualization technologies may offer unique information access and integration solutions in the future. Improvements in “integration” of information would support more effective analysis of global data and would also help developing countries to convert the knowledge they gather (from global and local sources) into effective action much more rapidly and proficiently.

## Methods

### *Data sources*

In order to assess and understand the global research environment, three data sources were the most useful – UNESCO (United Nations Educational, Scientific and Cultural Organization) Research and Development data (1996-2002), the Institute of Scientific Information publications listings for January 1998 through March 2003, and the World of Learning 2002 reference volume. Each data source also had significant limitations, which are presented.

### *UNESCO Research and Development data (1996-2002)*

UNESCO defines research and experimental development (R&D) "as any creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man [sic], culture and society, and the use of this stock of knowledge to devise new applications." Data for global R&D investments were taken from three key reports and cover:

- Gross domestic expenditure on R&D,
- Sources of funds, and
- R&D personnel.

Gross domestic expenditure on R&D is defined (by UNESCO) as total intramural expenditure on R&D performed on the national territory during a given period. It includes R&D performed within a country and funded from abroad but excludes payments made abroad for R&D. Gross domestic expenditure data were examined in PPP$ (Purchasing Power Parity dollars), a contrived international currency measure that allows for aggregation and comparison of financial data across countries. In essence, PPP$ will buy the same basket of goods and services in any country. Summaries are also presented of UNESCO calculations of a) gross domestic expenditure as a percent of gross domestic product (GDP) and b) gross domestic expenditure per capita (in PPP$).

Research expenditures by sources of funding examine the following sectors – business enterprise, government, higher education, private non-profit, and funds from abroad. These are presented as percentages of the total funding. If necessary, precise definitions of these sectors can be found within the definition of "Gross domestic expenditure on research and development (GERD)" in the *Technical Guidelines* of the Science and Technology section of the UNESCO Institute for Statistics web site.

In terms of personnel, UNESCO R&D data are divided into three categories:

- Researchers, which includes post-graduate students,
- Technicians and their social science and humanities equivalents, such as research assistants, and
- Other supporting staff, which includes administrators, secretaries, clerks and craftspeople whose activities are a direct service to R&D.

The data have significant limitations. One is that UNESCO provides data for only 91 countries, representing 38% of the 241 countries listed by International Standards Organization (see Coverage and Presentation below). Significant manual work was necessary to identify the countries covered and missing in the UNESCO reports. Further, UNESCO does not provide R&D information for all countries every year and there is no single year in which comparable data are available for all 91 countries. For many countries, data are available for only one or two years. Data was used for the most recent available year in the calculations and tables, even though that meant averaging across different years in different countries. Additionally there are many notes on the original UNESCO tables highlighting other limitations. For example, for some countries the data are provisional (e.g. Austria), exclude certain types of research (e.g. Hungary excludes military research) or expenditures (e.g. USA excludes capital expenditures), or do not calculate personnel as full-time equivalents (e.g. Cuba).

### *Institute of Scientific Information publications listings (January 1998-March 2003)*

Thompson ISI (Institute of Scientific Information) maintains extensive databases containing the full texts of articles written in over 8,700 scholarly and technical journals. Searches were conducted of the author address lists included in Web of Science, which is constituted of three indexes: Science Citation Index Expanded (SCIE), Social Science Citation Index (SSCI), and Arts and Humanities Citation Index (AHCI). For each paper the number of authors from each country were counted. These data were gathered for a period of just over five years of publications from January 1998 through March 2003.

An important limitation here is that there is no “Country” field in the Thompson ISI records, so that data collection required a laborious series of word matches between individual countries and the address fields in the author listings. The counts reflect the number of authors, as well as the number of papers. The same paper will have been counted for each author and each author will also have been counted for each paper they have contributed to. Country names (and variations) were searched only in English, so Oesterreich would have been missed when searching for Austria, for example. Further, the challenges introduced by different spellings (St. or Saint) and spelling mistakes were not negligible, and while measures could be taken to reduce the impact of these mistakes (such as using the smallest possible roots and name variations for searches), it was not possible to completely eliminate them or to easily assess how significant an impact they might have. Avoiding double counting of journals listed in more than one index was also time-consuming.

### *World of Learning 2002 reference volume*

Data for the numbers of Learned Societies, Research Institutes, Universities and other institutes of higher learning, Libraries and Archives, and Museums and Art Galleries are available on 184 countries from the reference volume World of Learning. Data was gathered from the 2002 volume, which reflects the conditions of those organizations in 2001.

The limitations of these data are that they do not indicate the size, reputation or influence of the institutions represented. In addition, overarching structures also influence the counts. France and Italy, for example, each have a single state sponsored institute for research. Both of these institutes are comprised of hundreds of individual, virtually independent centers of research at different locations, with substantial independent budgets and independent global recognition. It is both possible and conceptually sensible to count these centers separately. Other countries, such as Israel, identify a single state sponsored research institute with only a list of fields of study covered and indications of subsidiaries. In this case, only one institute would be counted as opposed to the 300+ of France or Italy. Another limitation is that the cost of accessing these data electronically is prohibitive, so that searching a 2000+ page book manually was time-consuming and more prone to error.

### *Coverage and Presentation*

The International Organization for Standardization (ISO) list of "English country names and code elements" (based on the ISO 3166-1 standard for country names) was used to determine all countries in the world. The ISO list was compared against the data sources, and a total of 45 ISO countries were excluded from coverage in this report – 34 because they were not listed as unique countries in the UNESCO or World of Learning sources (many are likely to have been included in the statistics for another country, e.g., Guam, Puerto Rico, American Samoa are likely to have been included in the US statistics) and 11 because they were not in the World Bank economic groupings used (see below). Thus the tables represent data from 196 of the total 241 countries listed by ISO. In each table information is presented both on the number of countries not included by the data source (countries missing) and the number of countries for which data were missing for a particular statistic (missing data).

Data is presented in economic groupings based on the World Bank Group document "Country Groups By Income". The four groups are based on 2003 gross national income per capita (in U.S. dollars) and include:

- Low-income economies - $765 or less,
- Lower-middle-income economies - $766 - $3,035,
- Upper-middle-income economies - $3,036 - $9,385, and
- High-income economies - $9,386 or more.

The World Bank Group states, "Classification by income does not necessarily reflect development status," but no single authoritative source was found that classified all countries by development status.

## Results

The first thing to note about the tables is the large number of countries for which no data exist, especially in the UNESCO listings, which cover only 91 of the 196 countries. In contrast, 195 countries were reviewed when searching the ISI publications (the Democratic Republic of Congo was mistakenly included with the figures for the Republic of Congo), and the World of Learning volume covers 184 countries. For the UNESCO Research and Development expenditure data, no data are available for 78% of the low-income economies, 49% of the lower-middle-income economies, 44% of the upper-middle-income economies and 35% of the upper-income economies (Tables 1-3). Because of the large proportion of missing countries, the conclusions drawn from the UNESCO data must be treated with caution.

Keeping the caveat about missing countries in mind, many of the trends were what would be expected. Thus the richer the country grouping, the greater the R&D expenditure in all categories (Table 1), the greater the proportion of research funded by business compared to government (Table 2) and the greater the number of research and development personnel (Table 3).

Table 1: Research and Development Expenditures, by Income Economy

| | Gross in PPP$ (000 000) | Per Capita in PPP$ | As % of GDP |
|---|---|---|---|
| **Low-Income Economies (n=13; 46 countries missing)[a]** | | | |
| Median | 20 | 4 | 0.19 % |
| Range | 0.6 (Zambia) – 20,039 (India) | 0.1 (Zambia) – 19.7 (India) | 0.01 (Zambia) – 0.75 (Uganda) |
| Missing Data | 4 | 4 | 4 |
| **Lower-Middle-Income Economies (n=28; 27 countries missing)[b]** | | | |
| Median | 270 | 10 | 0.35 % |
| Range | 10 (Honduras) - 55,543 (China) | 2 (Honduras) – 86.8 (South Africa) | 0.05 (Honduras) – 1.16 (Russian Federation) |
| Missing Data | 4 | 4 | 3 |
| **Upper-Middle-Income Economies (n=19; 15 countries missing)[c]** | | | |
| Median | 383 | 46 | 0.47 % |
| Range | 12 (Trinidad & Tobago) – 3,271 (Mexico) | 1.0 (Trinidad & Tobago) – 193 (Czech Republic) | 0.14 (Trinidad & Tobago) – 1.31 (Czech Republic) |
| Missing Data | 1 | 1 | 1 |
| **Upper-Income Economies (n=31; 17 countries missing)[d]** | | | |
| Median | 5,266 | 462 | 1.94 % |
| Range | 39 (Cyprus) – 274,642 (USA) | 18.9 (Austria) – 1,083 (Sweden) | 0.08 (Bermuda) – 4.96 (Israel) |
| Missing Data | 4 | 4 | 2 |

**Table 2: Percentage of Research & Development Funds from Different Sources, by Income Economy**

| | Business enterprise | Government | Higher education | Private non-profit | Funds from abroad | Not distributed* |
|---|---|---|---|---|---|---|
| **Low-Income Economies (n=13; 46 countries missing)** | | | | | | |
| Median | 13.5 | 55.5 | 0.4 | 0.0 | 4.5 | 0.0 |
| Range | 0.0 (Zambia) – 51.4 (Moldova) | 6.6 (Uganda) – 100.0 (Zambia) | 0.0 (Zambia) – 3.5 (Kyrgyzstan) | 0.0 (3 countries) – 0.3 (Uganda) | 0.0 (Zambia) – 90.3 (Uganda) | 0.0 (4 countries) |
| Missing Data | 9 | 9 | 9 | 9 | 9 | 9 |
| **Lower-Middle-Income Economies (n=28; 27 countries missing)** | | | | | | |
| Median | 24.4 | 50.6 | 1.6 | 0.0 | 5.3 | 0.0 |
| Range | 0.0 (Ecuador, Syria) – 57.6 (China) | 0.0 (Syria) – 90.6 Ecuador) | 0.0 (4 countries) – 100.0 (Syria) | 0.0 (9 countries) – 15.0 (Bolivia) | 0.0 (3 countries) – 40.1 (Paraguay) | 0.0 (15 countries) – 54.2 (Kazakhstan) |
| Missing Data | 11 | 11 | 11 | 11 | 11 | 11 |
| **Upper-Middle-Income Economies (n=19; 15 countries missing)** | | | | | | |
| Median | 24.9 | 48.2 | 0.7 | 0.0 | 4.1 | 0.0 |
| Range | 0.0 (Mauritius) – 54.4 (Slovakia) | 13.5 (Malaysia) – 94.7 (Mauritius) | 0.0 (5 countries) – 35.7 (Uruguay) | 0.0 (10 countries) – 7.1 (Latvia) | 0.0 (Trinidad & Tobago) – 55.1 (Panama) | 0.0 (12 countries) – 76.6 (Malaysia) |
| Missing Data | 4 | 4 | 4 | 4 | 4 | 4 |
| **Upper-Income Economies (n=31; 17 countries missing)** | | | | | | |
| Median | 52.5 | 35.9 | 2.6 | 0.0 | 6.6 | 0.0 |
| Range | 17.5 (Cyprus) – 72.4(Japan) | 19.6 (Japan) – 66.5 (Cyprus) | 0.0 (Italy) – 11.0 (New Zealand) | 0.0 (26 countries) – 4.6 (Cyprus) | 0.0 (USA) – 24.7 (Greece) | 0.0 (26 countries) – 1.1 (Denmark) |
| Missing Data | 4 | 4 | 4 | 4 | 4 | 4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Range | 17.5 (Cyprus) – 72.4(Japan) | 19.6 (Japan) – 66.5 (Cyprus) | 0.0 (Italy) – 11.0 (New Zealand) | 0.0 (26 countries) – 4.6 (Cyprus) | 0.0 (USA) – 24.7 (Greece) | 0.0 (26 countries) – 1.1 (Denmark) |
| Missing Data | 4 | 4 | 4 | 4 | 4 | 4 |

**Table 3: Research & Development Personnel, by Income Economy**

| | Researchers Per Million Inhabitants | Technicians Per Million Inhabitants | Other Supporting Staff Per Million Inhabitants* |
|---|---|---|---|
| **Low-Income Economies (n=13; 46 countries missing)** | | | |
| Median | 47 | 33 | 40 |
| Range | 2 (Senegal) – 581 (Kyrgyzstan) | 3 (Senegal) – 1,287 (Moldova) | 1 (Congo, Madagascar) – 353 (Mongolia) |
| Missing Data | 0 | 0 | 0 |
| **Lower-Middle-Income Economies (n=28; 27 countries missing)** | | | |
| Median | 411 | 206 | 324 |
| Range | 29 (Syria) – 3,494 (Russian Federation) | 1 (Peru) – 2,393 (Cuba) | 9 (Brazil) – 3,331 (Cuba) |
| Missing Data | 2 | 9 | 14 |
| **Upper-Middle-Income Economies (n=19; 15 countries missing)** | | | |
| Median | 684.4 | 302.5 | 363.0 |
| Range | 4 (Oman) – 2,303 (Lithuania) | 0.0 (Oman) – 882 (Trinidad & Tobago) | 21 (Uruguay) – 613 (Lithuania) |
| Missing Data | 2 | 7 | 10 |
| **Upper-Income Economies (n=31; 17 countries missing)** | | | |
| Median | 2,619 | 535 | 563 |
| Range | 41 (Macau) – 7,110 (Finland) | 23 (Macau) – 2,594 (Denmark) | 134 (Kuwait) – 725 (Belgium) |
| Missing Data | 1 | 21 | 23 |

The analysis of ISI publication data produced results in line with those in Table 3, namely that of the over 21,000 authors identified, more were likely to come from the richer country groupings. But it was of interest that at least one author was found from all but two of the countries searched.

Table 4: Country Affiliations of All Authors of All Papers Listed in Web of Science Jan. 1998 – Mar. 2003, by Income Economy

| | All authors of all papers |
| --- | --- |
| **Low-Income Economies (n=59)** | |
| Median | 236 |
| Range | 4 (Somalia) – 104,865 (India) |
| **Lower-Middle-Income Economies (n=55)** | |
| Median | 737 |
| Range | 1 (Kiribati) – 153,753 (Russian Federation) |
| **Upper-Middle-Income Economies (n=34)** | |
| Median | 1,375 |
| Range | 3 (St. Vincent & Grenadines) – 60,207 (Poland) |
| **Upper-Income Economies (n=48)** | |
| Median | 19,169 |
| Range | 4 (Aruba) – 2,060,522 (USA) |

More noteworthy are the results in Table 5 on the institutes of higher learning and associated organizations. Here the discrepancies

**between the different income groupings are much less marked (and the data are more complete). Overall, however, there are still significant discrepancies, with some countries having no or few such institutes and organizations and others being richly endowed.**

**Table 5: Institutes of Higher Learning and Associated Organizations, by Income Economy**

| | Learned Societies | Research Institutes | Universities & other institutions of higher education | Libraries and Archives | Museums and Art Galleries |
|---|---|---|---|---|---|
| **Low-Income Economies (n=57, 2 countries missing– Equatorial Guinea, Guinea-Bissau)** | | | | | |
| Median | 2 | 9 | 6 | 4 | 2 |
| Range | 0 (16 countries) – 105 (India) | 0 (6 countries) – 168 (India) | 0 (Sao Tome & Principe) – 81 (India) | 0 (Chad, Yemen) – 49 (Pakistan) | 0 (6 countries) – 43 (India) |
| **Lower-Middle-Income Economies (n=50, 5 countries missing – Cape Verde, Djibouti, Micronesia, Serbia & Montenegro, Vanuatu)** | | | | | |
| Median | 7 | 16 | 13 | 8 | 9 |
| Range | 0 (6 countries) – 113 (China) | 0 (5 countries) – 889 (Russian Federation) | 0 (Maldives) – 407 (Russian Federation) | 1 (Kiribati, Suriname) – 96 (Russian Federation) | 0 (Palestine) – 184 (Russian Federation) |
| **Upper-Middle-Income Economies (n=30, 4 countries missing – Dominica, Palau, St. Kitts & Nevis, St. Vincent & Grenadines)** | | | | | |
| Median | 4 | 10 | 8 | 7 | 6 |
| Range | 0 (3 countries) – 153 (Poland) | 0 (5 countries) – 196 (Poland) | 1 (3 countries) – 88 (Mexico) | 1 (Antigua & Barbuda) – 63 (Poland) | 0 (3 countries) – 111 (Hungary) |
| **Upper-Income Economies (n=47; 1 country missing– Cayman Islands)** | | | | | |
| Median | 13 | 14 | 11 | 11 | 6 |
| Range | 0 (6 countries) | 0 (5 countries) | 0 (Andorra) – | 0 (French | 0 (Aruba, New |

| | | | | | |
|---|---|---|---|---|---|
| Range | 0 ([illegible] countries) – 153 (Poland) | 0 ([illegible] countries) – 196 (Poland) | 1 ([illegible] countries) 88 (Mexico) | 1 (Antigua & Barbuda) – 63 (Poland) | 0 ([illegible] countries) 111 (Hungary) |
| **Upper-Income Economies (n=47; 1 country missing– Cayman Islands)** | | | | | |
| Median | 13 | 14 | 11 | 11 | 6 |
| Range | 0 (6 countries) – 461 (UK) | 0 (5 countries) – 439 (Italy) | 0 (Andorra) – 1,166 (USA) | 0 (French Polynesia) – 299 (UK) | 0 (Aruba, New Caldonia) – 216 (Italy) |

The overall points to make by presenting these data are a) how difficult it is to easily get a good overview of the global research situation from existing sources and b) how marked and challenging the inequalities in research capacity between countries are. The five tables presented together here are essentially all that is currently available and accessible. The implications for the Information Science and Technology field are discussed next.

## Discussion

### *Information access and integration challenges*

A particularly illuminating part of the effort to assess and understand the global research environment was learning how difficult it was to find relevant data, how incomplete and unable to be compared the available data were (in spite of authoritative sources), and how frustrating it was to try to effectively present data that could be viewed and interpreted in many ways while simultaneously being messy and incomplete. In spite of a great deal of searching and a naïve expectation that many others would previously have found the global research environment worthy of interest and exploration, the three data sources presented here were all that could be found.

Data were considered from other sources, but were not included for reasons primarily to do with their limited scope. The Organisation for Economic Co-operation and Development (OECD) produces data related to tertiary attainment grouped by disciplinary areas. Analysis of high level research degrees in specific disciplines could have been useful to compare with national research expenditures and publication data, but OECD membership is limited. Data are available only for the 30 member states and Israel, and those member states reflect a particularly western/northern bias (23 from Europe, 3 from North America, and Japan, Korea, Australia and New Zealand). Membership in prestigious academic societies could have also been instructive about the geographic distribution of internationally recognized scholars. The country affiliations of the member rosters of both the American Academy of Arts and Sciences and The Royal Society were reviewed. Both societies elect “foreign” members, and the data appeared to support the results presented here, but given that each society has a clear national association (United States and United Kingdom, respectively), it did not seem reasonable to include the data in this global survey.

Aside from challenges in identifying sources, it was an extremely laborious process to gather the data (as outlined in the methods section). The UNESCO data came in three reports, which needed to be manually combined and re-processed in order to facilitate proper analysis. Author publication data was gathered manually because country affiliations were embedded in the author fields along with names, titles, affiliations, and contact information, and they could not be easily analyzed. The World of Learning data was manually aggregated from a 2000+ page volume because fees for electronic access to data were prohibitive.

### *Boundary issues*

Throughout the data collection and analysis process, a persistent thought arose again and again: “There must be a better way.” This type of global, diverse, and distributed information will become increasingly necessary in the 21st century, and the skills of information architects, information retrieval specialists and information science trained domain specialists will be critical for providing more tools to researchers and practitioners seeking information to support complex problem-solving activities.

The inconsistencies in the data can most probably be attributed to a lack of standardization in data collection across countries, a lack of resources within countries for collecting the data in the first place, and/or political issues restricting or prohibiting the release of data. In general, these are areas beyond the scope of information science and technology – problems for statisticians, federal administrators, or international nongovernmental organization program managers to solve. These are issues more of compliance and advocacy than tractable problems for information scientists. The Partnership in Statistics for Development in the 21st Century (Paris21), currently managed by the OECD, demonstrates that such efforts are already underway (http://www.paris21.org/). On the other hand, there are still large pieces of reconciling data inconsistencies and facilitating better data collection processes that can benefit from the principles of information science and the technology developed thereby. There is a boundary question here that cannot be easily answered, but the information science and technology field may do well to explore the perimeter as it looks forward into the next few decades.

### *Parallel challenges at different scales*

The most straightforward finding from the data is also the most predictable: the higher the economic status of a country, the greater the commitment of funds and personnel to R&D, and the greater the number of authors publishing in research journals. The lower R&D measures for lower-income economies are undoubtedly directly related to Kofi Annan's call for increased independent science and technology capacity in developing countries.

This vision of a situation where "every nation gains full access to this broader world community of science and has the opportunity to develop an independent science capability" (Annan, 2004) requires a two-pronged information solution for developing countries. First, it needs improved information retrieval systems, technologies and policies to facilitate greater access for developing countries to the existing research around the globe (including the ability to access and/or translate relevant research in multiple languages). Improved access to information is also a critical component in getting a more complete sense of the global research environment as a whole. Second, the vision requires simple ways for combining and analyzing diverse information from multiple resources in order for developing countries to turn that knowledge into effective action. Integration challenges plague the assessment of the global research environment as well. Solutions in this area would greatly reduce the amount of labor necessary to integrate related data from three distinct UNESCO reports, for example. Information scientists can assist with both types of solutions at both scales of information need. The following technologies and information science concepts provide a short list of strategies that might contribute to successful solutions. The ability of these tools to assist, however, relies on: a. promotion and adoption of the technology or concept by information providers; and, b. education of the consumers of information as to how to take advantage of improved information delivery as provided by these tools.

*Information access and exchange strategies*

**RSS – "Rich Site Summary" or "Really Simple Syndication" (RSS) technology allows for immediate receipt of relevant web content rather than time consuming searching. As more content providers of research and data enable RSS technology, searchers of information will be able to receive just the type of information they need and have new information delivered to them as it is available, rather than having to search it out. This will enable more rapid and active sharing of information within and between countries, and is already being discussed actively in the context of science publishing (Hammond, 2004).**

**OAI-PMH and OpenURL – The Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) enables those information providers who code their data properly to make their information much more visible in more places that consumers of that information are likely to be searching in. UNESCO is now considering how to make its CDS/ISIS (Computerized Documentation System/Integrated Software for Information Storage) database software OAI-compliant (Jayakanth, 2005). The OpenURL standard enables the use of a standard URL (web site address) by which the same web content/information can be found even if the content itself is moved to another server. Information seekers will not waste time searching for a new URL to find updates to important information. Recent speculation on new uses for OpenURL are also encouraging (Chudnov, 2005).**

**Open Access Publishing – The movement to develop high quality, peer reviewed scientific journals available at no cost to the reader via the Web also holds great promise. In a very thorough exploration of open access (OA) and the "global knowledge commons" in 2005, it was concluded that "OA [open access] is immediately available and it can provide equitable access as well as professional inclusion for developing country science" with continued dedication by all parties (Chen, 2005). While not an "information science" tool per se, the OA movement is facilitated in many ways by tools crafted by the field.**

*Information integration strategies*

**XML – EXtensible Markup Language allows for the transfer of data in a platform-independent state (instead of Excel, Word, CSV, etc.)**

where distinct parts of the content can be labeled (country name, data type, etc.). Two sets of data, for example, can then be easily integrated by mapping the data sets through any common labels. If information providers offer their content in this structured but simple code, more consumers of information will be able to take the data/information they are interested in and easily integrate it into whatever system they are using to manage their own activities. Unique domain- or region-specific schemas, based on ontologies determined by information seeking and use research, can facilitate the rapid translation of information from one system, region, national department, country, or language to another. Some projects to develop an International Development Markup Language have been initiated but not been successful (IDML Initiative: http://www.idmlinitiative.org/). It may be useful to explore these efforts to learn from them.

Taxonomies and Ontologies – Taxonomies establish hierarchies of subjects, objects or ideas based on shared characteristics, while ontologies establish hierarchies of relationships between agents, objects, actions and settings/contexts. As the creative development of these tools expand, they can be used to develop sophisticated schemas for sharing information about complex, interconnected subjects like sustainable development, public health or national security. They can also facilitate automated searching that will allow the discovery of related information that an information seeker may not have found otherwise. A researcher may not be familiar with all the disciplines that factor into a multi-disciplinary, inter-connected problem, and might not know best how to search for relevant information in other fields. "Discovery" of other information can therefore be critical. Utilizing these ontologies with "smart" XML-based information-sharing protocols, like the Resource Description Framework that is at the heart of semantic web technology (Berners-Lee, 2001), will facilitate the automation of aggregating relevant data and conducting preliminary analysis, thereby increasing the ability of nations and supra-national organizations to make important connections and linkages more rapidly.

### *Information needs, seeking behavior, and use research*

There are also challenges in linking research and practice – disseminating research in such a way as to effectively inform decision-making (e.g. farmers deciding whether to purchase genetically modified seed, policymakers deciding agriculture policies). The challenges apply to all countries, but may be different in extent and form in developing countries. More research on information needs, seeking behavior, and use/implementation is necessary to determine what specific contributions information science can make. Such research could then support the innovative application of ontology or taxonomy development to describe and structure complex, multi-disciplinary issues in ways that will facilitate information flow. Much research has already been conducted that could be placed into the larger global framework suggested by Kofi Annan and encouraged here, but more is certainly needed.

### *Information visualization*

The tables included here present data in the simplest and most easily comprehensible way. They barely hint, however, at the actual depth and diversity of the measures that have been aggregated and analyzed in the preparation of this paper. Research in a global environment occurs within many related and occasionally conflicting larger contexts, which it is usually only possible to describe via lengthy narratives and collections of tables and charts. Current developments in information visualization (in both the two-dimensional graphics arena and the three-dimensional field inspired by electronic gaming technology) hold great promise for presenting greater amounts of information within a comprehensible framework. Imagine mapping health, economic, education, and agricultural research into a single three-dimensional environment that could be “walked around in” like a video game. Heretofore unrecognized connections and solutions may appear in these new information visualizations which have the potential to launch an entirely new era of problem-solving techniques for complex issues like sustainable development or global public health.

### *Unexpected advantages*

What was encouraging in the results was the unexpected discovery that many of the poorer countries have an institutional foundation in terms of universities, research institutes and libraries (Table 5). These institutions may become allies for information scientists dedicated to solving information problems for developing countries. They may provide conceptual and cultural frameworks for guiding the work. These institutions may also prove to be useful in assisting with research about the way information is shared and utilized in their region in order to determine the true information needs in various countries.

At the global level, a number of organizations have already committed themselves to monitoring and supporting international information issues, including the Global Knowledge Partnership (http://www.globalknowledge.org/), the Global Research Alliance (http://www.research-alliance.net/), the International Federation of Library Associations and Institutions (http://www.ifla.org/), the UNESCO Observatory on the Information Society (http://portal.unesco.org/ci/en/ev.php-URL_ID=7277&URL_DO=DO_TOPIC&URL_SECTION=201.html), and the World Summit on the Information Society (http://www.itu.int/wsis/). These existing structures provide additional support for developing "independent capacity" and "reservoirs of knowledge."

## Conclusions

If the world is serious about addressing the issues that Kofi Annan talks about in his editorial, the results of the efforts presented here could potentially serve as partial baseline for measuring progress – of both the independent research capacity and knowledge production of individual countries, but also of the ease (or lack thereof) in finding, gathering, integrating and presenting the relevant data. In the meantime, these data have generated a significant agenda and task list for the information science and technology field. It is the province of many disciplines to produce research that can form the basis of solving practical problems. It is the role of information scientists, however, to make this information easy to find, easy to share, and easy to integrate with other information in complex local environments where it can be transformed into effective action.

With improved access, exchange and integration, global and local information systems could enable the positioning of research in agriculture, computer science, environmental science, public health, education, sociology, security, economics and countless other disciplines in ways that would put more relevant information rapidly and efficiently into the hands of those who need it and reveal unexpected connections to other topics and dimensions of complex problems. These improvements would impact the assessment of the global research environment itself, the ability of the world at large to generate successful reservoirs of knowledge and expertise, and the ability of developing nations to strengthen their own capacity for turning knowledge into real solutions.

The theory and methods for integrating the many dimensions of complex problems and converting research into productive policy and action are being developed by scholars working in Integration and Implementation Sciences. These scholars work with developed

**and developing nations alike to further understand and harness the operations and effects of systems thinking, participatory methods and information management, exchange and implementation to guide large-scale, complex problem-solving. In the case of developing nations, there is an opportunity to utilize the institutional foundations uncovered in the research presented here to help shape their future establishment of a research infrastructure that responds to their own complex, cross-disciplinary needs within the interconnected global environment.**

**As we move to a global, integrated and ever more complex system of societies, economies and infrastructures, the information solutions found to address the challenges in assessing and understanding the global research environment will undoubtedly serve as models for other complex, large-scale problems we have yet to imagine.**


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