Understanding e-Science—What Is It About?

Claudia Koschtial

Abstract Our daily life has experienced significant changes in the Internet age. The emergence of e-science is regarded as a dramatic one for science. Wikis, blogs, virtual social networks, grid computing and open access are just a brief selection of related new technologies. In order to understand the changes, it is necessary to define these aspects of e-science precisely. Right now, no generally used term or common definition of e-science exists, which limits the understanding of the true potential of the concept. Based on a well-known approach to science in terms of three dimensions—human, task and technology—the author provides a framework for understanding the concept which enables a distinctive view of its development. The concept of e-science emerged in coherence with the technological development of web 2.0 and infrastructure and has reached maturity. This is impacting on the task and human dimensions as in this context, the letter "e" means more than just electronic.

Keywords e-Science · Open access · Grid computing · Science 2.0

1 Introduction

The "e" in combination with a number of well-known terms implies a transformation into online networks and the usage of information technologies, which has evolved in both private and professional life. Science, in its most general meaning as scholarship comprising all disciplines, has also been subject to this transformation. This development is being referred to as electronic/enhanced science, or e-science. The transformation may enable changes going beyond technology itself. According to Luskin, the big e means more than just electronic (Luskin 2012). Fausto et al. (2012) stated this more precisely: "Increasing public interest in science information in a digital and Science 2.0 era promotes a dramatically, rapid, and deep change in science itself". The goal of this paper is to review research as work in progress.

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The resulting literature analysis shows what and how science is changing due to the impact of using online networks and information technology.

The change in science can be traced back to the 1990s, when the concept of collaborative laboratories (collaboratories) evolved (Bly et al. 1997, p. 1). In 1996, the term cyberscience was sharpened by Nentwich (1999) who refers cyberscience to research activity which scientists were increasingly carrying out in the developing information and communication space. Taylor (1999) produced a definition close to this one: "e-science is about global collaboration in key areas of science, and the next generation of infrastructure that will enable it" and "e-science will change the dynamic of the way science is undertaken". The definitions mark just the beginning of an ongoing transformation. Most recent aspects of e-science contain open access or science 2.0, referring to the usage of web 2.0 technologies like social networks, blogs or wikis. The cited definitions share some elements: activity of research, scientists, infrastructure, collaboration, information and communication. Nevertheless, a common definition does not yet exist, and more diverse terms have emerged since the first occurrence of this concept. Understanding the potential and extent of the change requires an analysis of the concept itself. The present research is an initial step towards this, which can be used as a basis for designing a comprehensive framework of the concept of e-science in order to support the work of scientists.

The remainder of the paper is as follows: the second section presents related work and the research gap. The third section explains how the research has been carried out and how the concept is going to be analysed in order to derive a definition. In Sect. 4, the results of the analyses are presented, leading to a discussion in Sect. 5.

2 Related Work

Science defines one possible way to make reality understandable. Leaving behind myth and religion, the ancient Greek philosophy represented an early systematic examination of the world. It dates from 2500 years ago, when the society transformed in the search for education and elucidation. Schools evolved, so science was (and still is) closely connected to teaching (Schülein and Reitze 2012, 31 p.)

Nowadays, there is no common perception or description of the change comprised by the term e-science (Yahyapour 2018, p. 369). The literature often deals with open access or particular problems related to data availability. Shneiderman (2012, p. 1349) stresses the potential for understanding and rethinking how a phenomenon is analysed. He promotes methodologies that move away from laboratory to real-world conditions, especially to analyse areas like "secure voting, global environmental protection, energy sustainability, and international development" (Shneiderman 2012, p. 1349). Eastman approaches the underlying process of e-science in terms of data analysis. He formulates an observational-inductive model in order to reflect on Knowledge Discovery in Databases and Data Sensor High-Performance Computing Models without a theoretical basis. His idea sounds promising, but he provides few arguments for it (Eastman et al. 2005, 67 p.). Work and related organisational aspects of science like group learning and cooperative processes are addressed by Pennington (2011, 55 p.).

The mentioned literature is exemplary of a search in three literature databases (see Sect. 3.1). No general analysis of this area of discourse exists yet, so the usage and definitions of the terms have not been analysed before. Scientific understanding depends heavily on these papers, however. In order to sharpen the concept and identify discussed characteristics of e-science, the present authors performed the following literature analysis.

3 Research Approach

This section introduces the area of discourse and describes the applied methodology in Sect. 3.1. The applied research framework is then proposed in Sect. 3.2.

3.1 Research Field and Methodology

The research follows the method proposed by Fettke (2006, 257 p.). The research process itself demands that researchers have increasingly complex knowledge, which is usually beyond the borders of their own fields (Reinefeld 2005, p. 4). Two research challenges can be identified:

- The Internet can be used to search for and communicate information, but success in identifying information is not guaranteed.
- The vast amount of data is challenging to process in order to identify relevant content.

The mentioned challenges appear as well for the field of e-science. A couple of terms being used in e-science comprise some or all the elements mentioned above. The ones which have been mentioned so far are:

- e-science itself meaning electronic or digitally enhanced science (Hiller 2005, p.5);
- cyber infrastructure (Hey 2006);
- e-research (University of Technology Sydney 2013);
- cyberscience (Atkins 2005, 1 p.); and
- science 2.0 (Leibnitz 2012).

As these terms appear at different points in time, the meaning has to be reflected on and trends need to be considered in order to understand the circumstances in which they arose. Relevant literature was identified by searching the title, abstract and keywords for the terms “e-science”, “eScience”, “e-research”, “eResearch”, “science 2.0”, “cyberscience”, “cyberinfrasructure”, “grid computing” and “grid”

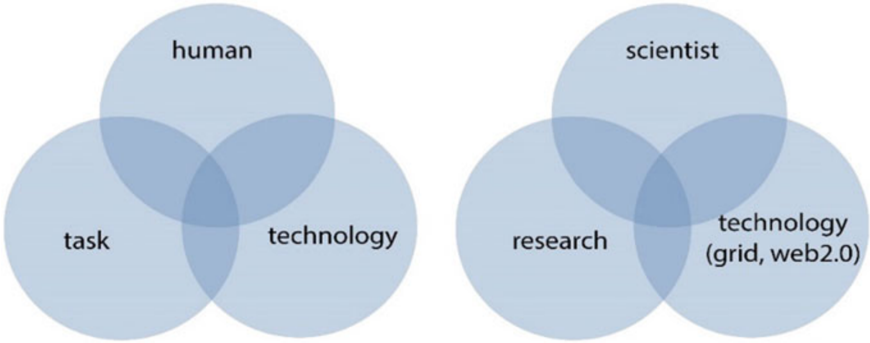

Fig. 1 Heirich's human—task—technology framework (Heinrich 1993, p. 8) and its adaption to the field of e-science

together with "e-science" in three databases: EBSCO Academic Search, ACM Digital Library and IEEE XPlore. To increase the amount of results, Google Scholar was also searched for titles in the period from 1994 to 2005. Digital humanities were excluded as it refers solely to e-science in the field of humanities.

3.2 Research Framework

A research framework is needed in order to identify the essence of the concept of e-science and differences between the terms being used.

Science 2.0 includes a range of topics. Shneiderman (2012, p. 1349) identified research on sociotechnical systems as the basis for an increasing collaboration. Heinrich (1993, p. 8) regards sociotechnical information systems as composed of human, task and technical dimensions; he sees such systems as open, complex and sophisticated. Figure 1 shows the general framework created by Heinrich (left-hand side) and its adaption to the context of e-science (right-hand side).

Regarding the given definitions, some initial characteristics can be extracted: scientists, information and communication, infrastructure, collaboration and research. In order to reflect all aspects of e-science, collaboration is added to the framework, as this was inherent in all definitions. Figure 2 shows the framework used.

4 Results

The literature search led to 148 definitions of the selected terms related to e-science. The most frequent definition was "e-science" (43%), followed by "grid"

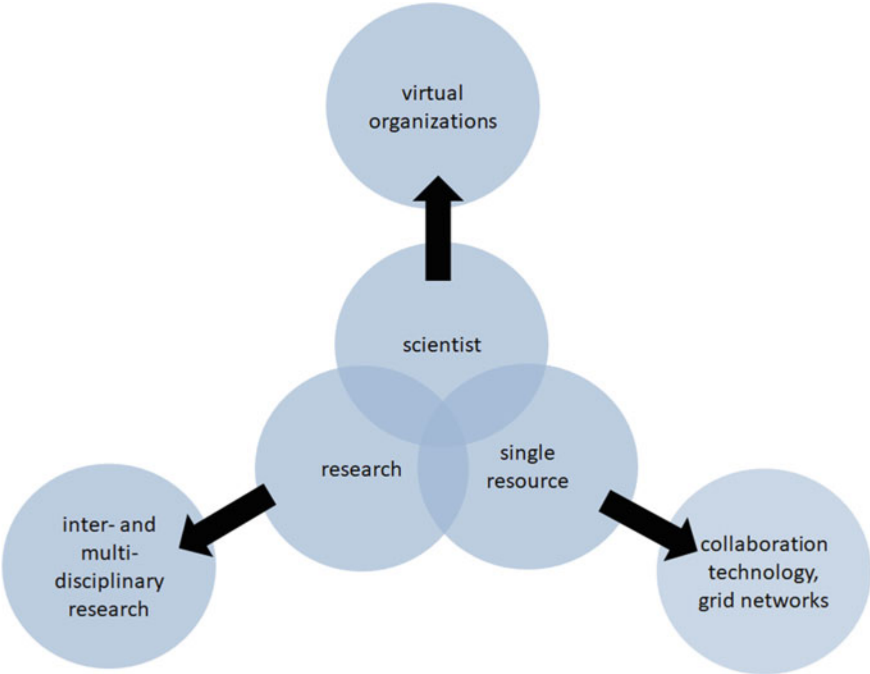

Fig. 2 E-science framework including collaboration

(32%), "science 2.0" (9%), "cyberinfrastructure" (8%), "e-research" (7%) and "cyberscience" (3%). Table 1 shows the number of definitions per year.

Figure 3 shows the occurrence of these terms over time.

In a second step, the authors analysed the development of the selected definitions over time and investigated whether the dimensions of the framework were mentioned in each definition. The following examples show key terms related to each dimension.

- Technical dimension:
  - Web 2.0 technologies as a single technology;
  - Networks and infrastructure as a collaboration technology.
- Task dimension:
  - Publishing, analysing or teaching as single tasks;
  - Collaborative projects which may have an interdisciplinary focus.

Table 1 Number of definitions per year

1998–2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
5	5	5	16	17	15	14	12	10	17	11	11	10

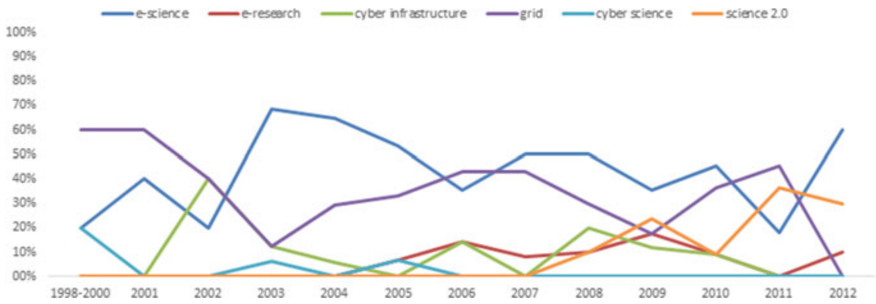

Fig. 3 Relative frequency of terms related to time

- Human dimension:
  - Researcher as human;
  - Virtual organisations like social networks.

The next step was to analyse the relations between the three dimensions, human, task and technology.

5 Discussion of Initial Results

Figure 3 shows that terms like cyberscience or cyberinfrastructure disappeared over time. The presence of the term e-science is relatively stable over the time, which can be seen as acceptance and establishment of this term. The frequency of the term grid is decreasing, which may hint that the technological side of the concept is already mature, established and needs no further development but that claim needs to be checked for the next years. Additionally, the funding period of the UK e-Science Core Programme stopped in 2006, resulting in a reduction of interest in the topic or at least resulting in a reduced amount of publications.

Figure 4 shows the content analysis of the definitions. The human dimension has an approximately stable occurrence over time. But technology is less often mentioned throughout the analysed period. Regarding technology, the number of definitions describing collaborative technology as a constitutive characteristic decreases over time. The term grid is also used less and less over time. Technology seems to be no longer a challenge, but an enabler. The single resource referring to web 2.0 technologies is stable over time. In the task dimension, collaborative/interdisciplinary research projects do not play a significant role. The intention of financial supporting institutions to encourage collaborative research may play an increasing role—but such a trend is not visible, yet. Research as task is an increasing part of the definitions, which might be a further hint that the technology itself is mature and the usage is becoming more important. This allows the concept to be used in more different fields.

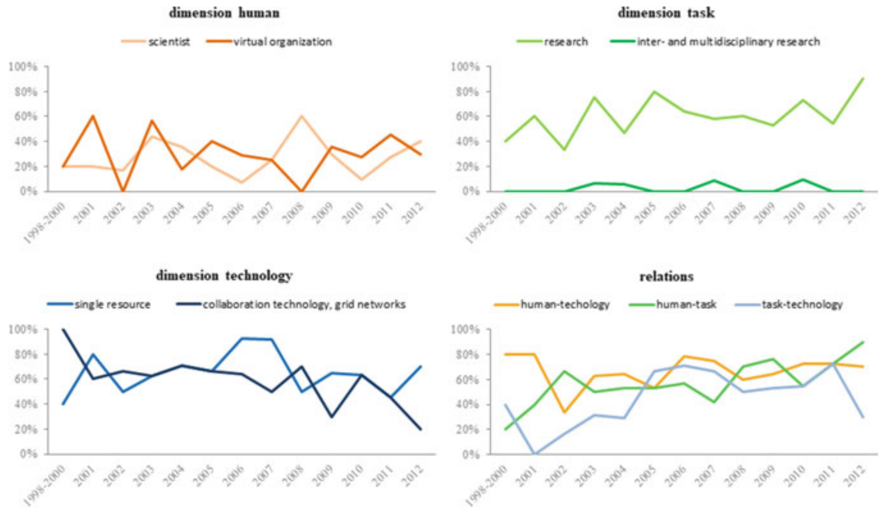

Fig. 4 Results of the analysis of the human, task and technology dimensions of e-science

Regarding the relations between the dimensions, an important link is emerging between task and technology. This may be understood as an indicator for increasing automation. Furthermore, the relation between human and task is the relation that is increasing most sharply.

The use of the selected terms varied by geographical location and in relation to public funding programmes in the respective area. The term e-science itself has been used by the UK e-science Core Programme from 1999 until 2006. Cyberinfrastructure comes from the USA, and e-infrastructure emerged in Europe. A further term appeared in 2005 on an initiative of the Australian Research Councils, which was entitled e-research. The focus here however is not on geographical differences and funding; this issue requires further investigation.

6 Conclusion

The aim of this paper was to show how the use of the term e-science is changing through a literature analysis. The initial results show that the concept of e-science changes over time. One aspect of the concept is technology, referring to infrastructure and single resources:

- Grid computing is "an important new field, distinguished from conventional distributed computing by its focus on large-scale resource sharing, innovative applications, and, in some cases, high-performance orientation" (Foster et al. 2001, p. 200).

- Web 2.0 technologies are an evolutionary stage in Internet use. Examples are virtual communities, blogs or wikis (Nentwich 2009).

Furthermore, e-science is oriented to tasks: processing vast amounts of data, searching for information or publishing content. The task of establishing collaborative projects is weakly represented in the analysed literature.

- Open access refers to “The first is a change in the publishing model to one more suited to the age of the Web; the second, a change in how scientists connect with society – their major funders through taxation” (e-science talk 2012).

Additionally, the scientist plays an important role in the concept of e-science in two ways:

- as a single researcher;
- as virtual communities, which exist only in the Internet. They form for a limited period in time as interdisciplinary groups of regional segregated elements (Mosch 2005). The key characteristic of such units is collaboration.

The changes related to e-science are apparent in all three of Heinrich’s dimensions. Important concepts like open access or the grid have been attributed to the different dimensions. Therefore, the potential of e-science is not reduced to electronification, but expanded to include redesign of tasks, the emergence of virtual organisations and the rapidly increasing importance of collaboration. Right now, the technology dimension still dominates the concept, but it is maturing and this will form the basis for further changes.

It seems necessary to do further research to analyse related technologies and tasks behind the concept of e-science in more detail in order to provide a sufficient base for scientists to be able to learn about the potentials of e-science and to convert those potentials into realised benefits.

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