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Communication

Four Decades of Systems Science Teaching and Research in the USA at Portland State University

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Abstract: Systems science is defined in general fashion, and a brief background is provided that lists some of the systems science-related societies, conferences, journals, research institutes, and educational programs. The Systems Science Graduate Program at Portland State University in Portland, OR, USA, is described in detail, including its history, curriculum, students, faculty, and degrees granted. Dissertation topics are summarized via word diagrams created from dissertation titles over the years. MS degrees, student placement, and undergraduate courses are also mentioned, and future plans for the program are described including its support for sustainability education.

Keywords: masters; doctorates; graduate students; student backgrounds

1. Introduction

Systems science [1] is the study of general principles that govern systems of widely differing types, and the use of systems ideas and methods in interdisciplinary/transdisciplinary research and socio-technical system design and management. Systems science draws on the natural and social sciences, mathematics, computer science, and engineering to address complex problems in both the public and private sectors.

For historical context, both the International Society for the Systems Sciences [2] and the system dynamics field were founded in 1956. The Hawaii International Conference on Systems Sciences [3] began its annual conference in 1967, and the International Journal of Systems Science [4] began publication in 1970. The first conference on system dynamics was held in 1976.

The need for interdisciplinary approaches to understanding and solving complex problems has received increasing attention in recent years, nationally and globally [5,6], and a focus on complex systems is central both to advances in science and engineering, real-world problem solving, and interdisciplinary research. Table 1 shows a small sample of institutes with a systems and complexity science focus. While the term interdisciplinary is most commonly used to describe systems-oriented endeavors, the terms crossdisciplinary, transdisciplinary, or multidisciplinary may be more apt or descriptive in some cases. Interdisciplinary usually involves an integration or synthesis of more than one discipline, whereas crossdisciplinary tends to refer to importing concepts from a different discipline in order to shift perspective without necessarily effecting an integration or synthesis. Trandisciplinary is often used to connote the idea of transcending specific disciplines and operating at a more holistic level, and multidisciplinary simply means employing multiple disciplines. Systems science is perhaps best described as transdisciplinary, although interdisciplinary is not incorrect.

Table 1. Example Systems-Oriented Research Institutes.

Name	Focus	Founded	Location
International Institute for Applied Systems Analysis [7]	Policy-oriented global problems	1972	Vienna, Austria
Santa Fe Institute [8]	Complex adaptive systems	1984	Santa Fe, NM, USA
New England Complex Systems Institute [9]	Complex systems	1996	Cambridge, MA, USA
Max Plank Institute for Dynamics and Self Organization [10]	Complex, self-organizing systems	2003	Gottingen, Germany
ARC Centre for Complex Systems [11]	Complex systems	2004	Australia

2. Background

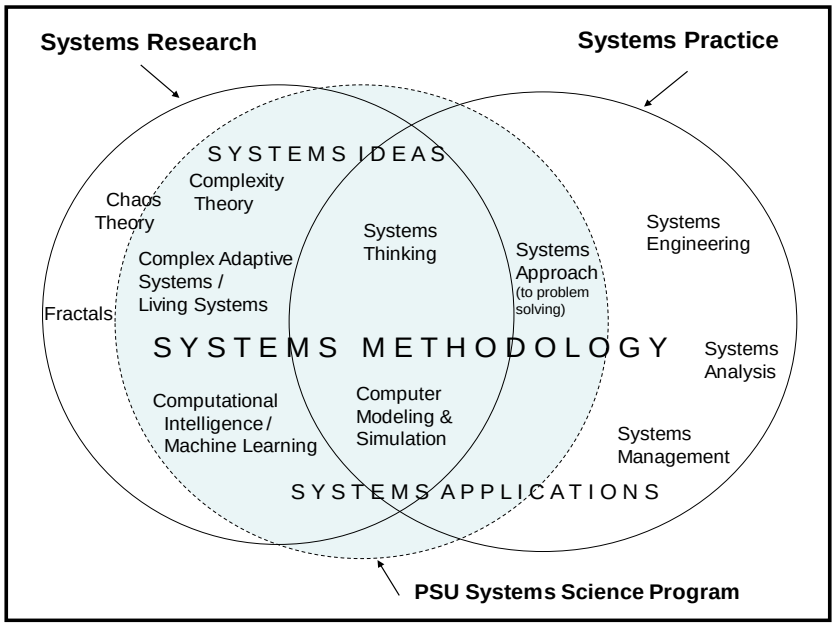
The Systems Science Graduate Program [12] (SySc) at Portland State University (PSU) was launched in 1970 as one of the first three doctoral programs offered when PSU became a university. The choice of systems science, along with environmental studies and urban studies, was motivated by a policy in the state of Oregon that prohibited duplication of doctoral programs at state-funded universities. So the initial doctoral programs were interdisciplinary and hoped to be at the cutting edge. The vision for SySc was to serve as a resource and focal point for integrative, systems-oriented teaching and research on the PSU campus and within the broader PSU community. The new doctoral programs initially reported directly to the dean of graduate studies.

In the mid-1980s, in order to strengthen the base of support for the program, SySc began working closely with nine academic units so as to allow students to minor in systems science while pursuing a primarily disciplinary Ph.D. This option was especially popular in Psychology, Engineering and Technology Management, and the Business School. In addition, of course, some students continued to major in systems science. As the state began to relax its policy regarding doctoral program duplication, many of the participating departments established their own Ph.D. programs. Consequently, SySc began transitioning to a stand-alone program. A Master of Science degree was added, and SySc began to offer interdisciplinary undergraduate courses in PSU's University Studies general education program.

Figure 1 shows that SySc is focused near the intersection of systems research and systems practice; it emphasizes systems ideas, methods, and applications (the shaded area within the dotted ellipse).

Systems engineering, analysis, and management are not a primary focus, nor are some of the more abstract systems theories such as chaos theory and fractals. This focus allowed the program to complement rather than compete with established departments, such as Electrical and Computer Engineering, Civil and Industrial Engineering, Computer Science, Mathematics, and Management Science. Of course, Figure 1 does not intend to fully represent the many subfields and theories relevant to systems science, as only a small sample of them are included within the "Systems Research" circle. Others not shown include graph theory, network theory, hierarchy theory, fuzzy logic, game theory, catastrophe theory, and control theory, to name a few.

Figure 1. Graphic depiction of the field of Systems Science and the PSU Systems Science Program.



2.1. Program Curriculum

The core SySc program has grown rapidly in recent years, fostering interdisciplinary collaborations within PSU, especially in computer science, electrical and computer engineering, urban studies, business, and public administration and policy; and also with strategic and community partners. Interdisciplinary graduate and undergraduate courses enable PSU students to learn systems ideas, theories, thinking approaches, as well as modeling and data analysis/data-mining methods.

Table 2 provides a brief summary of the courses and their role in the curriculum, by level, with graduate classes listed first. Recently, undergraduate (UG) sections have been proposed for several of the graduate classes in order to bolster their viability, and two new courses were initiated recently with both graduate and UG sections. For graduate courses, the role of each course is noted, including core, core methods, methods, or electives. The six UG classes that were developed in recent years are shown at the bottom of the table. Four of these new UG courses were developed by SySc graduate students. In addition to supporting the degree programs, eight of the graduate courses support graduate certificates, and this is noted in the table. The table also notes that four of the recently developed courses emphasize sustainability. Course frequency is provided as well, either high (annually), medium (bi-annually), or low (less often).

Table 2. Systems Science Curriculum Details.

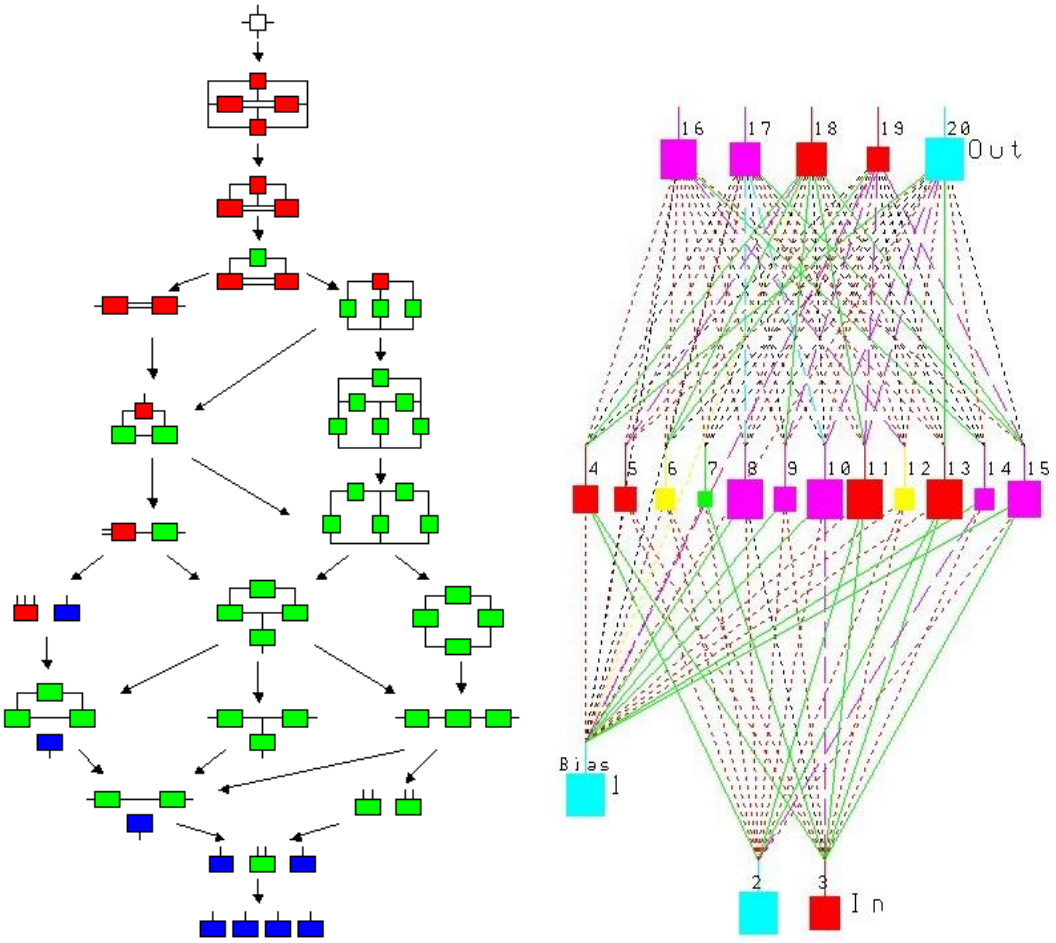
Level	Name	Role	Grad. Cert. *	Sustainability?	Freq	When Intro	Notes
Grad	Systems Theory	Core			H	70's	
Grad	Systems Approach	Core			H	70's	Renaming to Holistic Strategies for Problem Solving + add UG
Grad	System Dynamics	Core Methods	CM (req'd)		H	80's	
Grad	Game Theory	Elective			L	80's	Adding UG section to bolster
Grad	Artificial Life	Elective			L	80's	
Grad	AI: Neural Networks	Methods	CI (req'd)		L	80's	Instructor retired; some revamping needed
Grad	Discrete System Simulation	Methods	CM (req'd)		H	80's	
Grad	Quantitative Methods of Systems Science	Core Methods	CM & CI		L	90's	Major revision planned to incr. relevance to environ. scientists
Grad	Systems Philosophy	Elective			H	90's	Adding UG section to bolster
Grad	Discrete Multivariate Models	Core Methods	CM & CI		H	90's	
Grad	Business Process Modeling & Simulation	Methods	CM		L	90's	Outreach: business
Grad	Manufacturing System Simulation	Methods	CM		L	90's	Outreach: engineering & technology management
Grad	Agent Based Simulation	Methods	CM		H	2002	Outreach: social science, computer science
Grad	Systems Ideas and Sustainability	Elective		Yes	M	2009	Adding UG section to bolster interest
Grad	System Sustainability and Organizational Resilience	Elective		Yes	M	2011	Outreach: public policy
Both	Systems Thinking for Business	Elective			H	2013	Outreach: business
Both	Data Mining with Information Theory	Elective			H	2013	Outreach: computer science, social science, biomedicine
UG	Models in Science				H	2010	Create UG presence
UG	Indigenous and Systems Perspectives on Sustainability			Yes	H	2011	Ditto
UG	Intro. to Agent Based Modeling				H	2012	Ditto
UG	Modeling Social-ecological Systems			Yes	H	2012	Ditto
UG	Networks in Society				H	2013	Ditto
UG	Decision-Making in Complex Environments				H	2013	Ditto

***** CM = computer modeling. CI = computational intelligence.

Although the number of courses that focus explicitly on sustainability is just four, the field of systems science is well positioned to provide tools, methods, concepts, and models for helping to evaluate and foster sustainability, especially with respect to environmental stewardship and economic prosperity. Important principles are discussed in game theory (e.g., prisoner's dilemmas, evolution of cooperation), systems philosophy (e.g., open systems, externalities), and the systems approach (systems archetypes, such as limits to growth and tragedy of the commons).

Figure 2 depicts two frequently employed SySc methods in order to give a flavor of what is taught in SySc. Figure 2A shows the lattice of possible models of four variables as identified by the systems-oriented data analysis method called reconstructability analysis (RA) which is taught in the SySc course entitled Discrete Multivariate Models. RA was developed by Broekstra, Cavallo, Cellier, Conant, Jones, Klir, Krippendorff, and others (*c.f.* [13–15]). Figure 2B depicts an artificial neural network (ANN), a widely used artificial intelligence method taught in the SySc course entitled "AI: Neural Networks" (there are many good texts, *c.f.* [16]). ANNs are "trained" to predict outcomes given a set of inputs.

Figure 2. (**A**) Lattice of models of four variables in reconstructability analysis. A box is a relation; a line, with branches, uninterrupted by a box, is a variable. Arrows indicate decomposition and colors represent the number of variables contained in a relation. (**B**) Artificial Neural Network with a one hidden layer.



The top structure in Figure 2A is ABCD, which is the data itself; and the bottom structure is A:B:C:D, which is the independence model. The symbols in Figure 2A represent the various possible types of interactions amongst the four variables, as determined by considering their covariance structure. Fitness of models is assessed using information theoretic measures. Figure 2B indicates that the network has two inputs, five outputs, and three layers (input, hidden, and output). The weights connecting the nodes are determined through a training process employing input/output data records that seeks to minimize the error in the values at the output layer compared to the actual data, both for the dataset used for training and test data sets not used for training.

2.2. Comparison to other Systems Science Programs in the USA and Globally

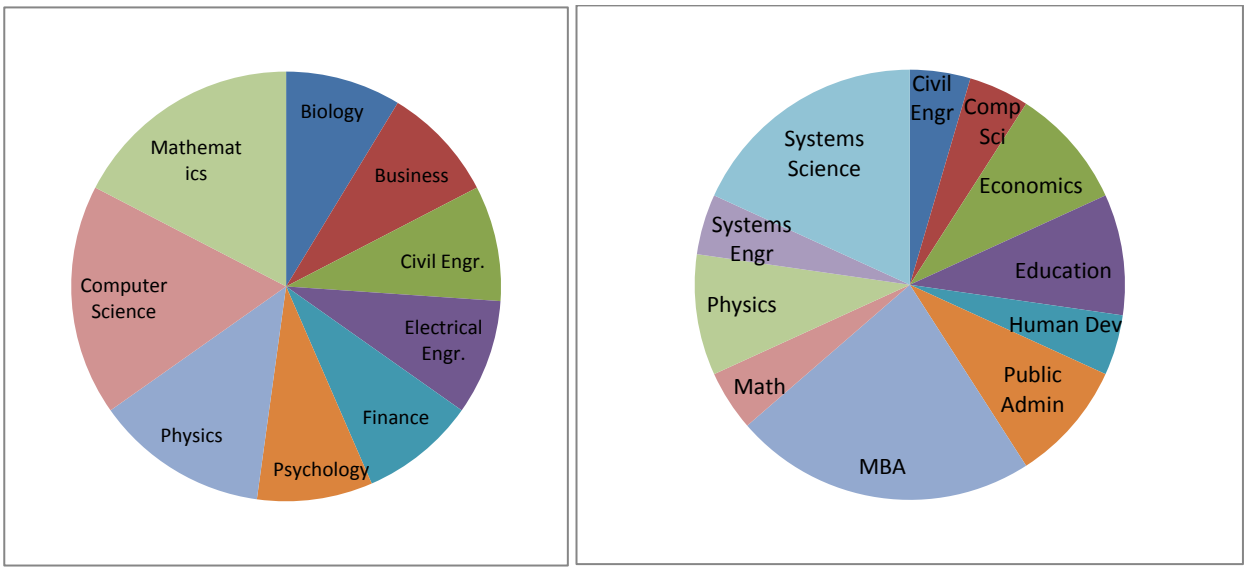
Dozens of systems science programs were created during the 1960s and 1970s, but only a few such programs remain today. Two examples in the USA include [17] at Binghamton University (SUNY) which has been closely linked with industrial engineering and automation for the past decade, and [18] at Washington University which is located in the Department of Electrical and Systems Engineering. Another example of a system science MS degree program can be found at the University of Ottawa, Canada [19]. Systems-oriented degree programs in Europe and Australasia tend to focus on systems engineering or complex systems mathematics. The SySc program at PSU shares with these other programs strong connections with engineering, computer science, and mathematics, but also provides a strong practitioner focus that features applications in biomedicine, health policy, and environmental sustainability.

2.3. Student Population

Our student population has varied over the years from two dozen students in the early years, to over 100 students a decade ago when departmental participation was in full bloom. During this time period, the core program also grew from ten to thirty students, and in recent years, the core program has increased to nearly 50 students: 30 doctoral students and 20 master's students. The non-core doctoral programs are being phased out, and there are currently less than 10 departmental students finishing up their research. "Core" SySc students take four to six core SySc courses and four to six elective SySc courses, plus elective courses across campus appropriate to support their research. A multi-disciplinary track was create several years ago in part to accommodate applicants seeking a more traditional interdisciplinary rather than transdisciplinary learning experience. Students in the multi-disciplinary track take three SySc core courses and three SySc electives, plus core sequences in two other field/disciplines such as environmental science, business, economics, computer science, or mathematics.

Our students come from an amazingly diverse collection of backgrounds. A recent review of the backgrounds of 44 core SySc students (27 Ph.D., 17 MS) revealed that they had earned their bachelor's degree in 27 different fields. Figure 3A shows the most common bachelor's degrees. Nearly all of the 27 doctoral students had already earned a Master's degree, as represented in Figure 3B. Two students had previously earned terminal degrees, one in architecture and one in medicine. Based on the subjective impressions of the faculty, having a more technical background tends to be correlated with successful completion, but communication skills, ability to focus, and time management seem to be nearly equally as important.

Figure 3. (**A**) Distribution of SySc Student Bachelor's Degrees, (**B**) SySc Student Master's Degrees.



(**A**) (**B**)

Table 3 provides data regarding the long term trends for annual graduation rates for doctorates and MS degrees, and, more recently annual graduate and undergraduate student credit hour generation rates. Note that most of the UG credit hours are generated by graduate students teaching UG courses, and that several of these courses were developed by the students.

Table 3. Annual Graduation Rate and Annual Student Credit Hour Generation Rate, by Decade.

	1972–79	**1980–89**	**1990–99**	**2000–09**	**2010–13**
Departmental Ph.D. Graduates	0	0.7	2.7	6.2	3.0
SySc Core Ph.D. Graduates	1.1	2.0	2.6	1.3	1.3
SySc MS Graduates	0	0	0	2.8	6
Graduate Student Credit Hours	n/a	n/a	n/a	900	865
Undergraduate Student Credit	0	0	0	156	480

2.4. Faculty

Until recently, core faculty consisted of 2.67 tenure lines, a 0.75 FTE fixed term faculty member, plus two to three adjunct faculty members who teach one or two courses per year (representing the teaching equivalent of another tenure line). Due to a recent retirement, however, that number has dropped to two tenure lines, plus adjunct faculty who teach one or two classes each. Core faculty members were George Lendaris, who focused on the systems approach and the use of neural networks and reinforcement learning for system control, Harold Linstone, who focused on technological forecasting and assessment, Martin Zwick, who focuses on systems philosophy and theory, game theory, and data mining using discrete mathematical models, Andy Fraser, who emphasized information theory and dynamical systems, and Wayne Wakeland, who focuses on the use of computer modeling and simulation to better understand the behavior of complex systems.

Besides coursework and student dissertation research, SySc faculty members also engage in externally funded research. In recent years, annual research expenditures have often exceeded $100K, which has helped to provide support for many graduate students. Table 4 provides a brief summary of externally funded research.

Table 4. Externally Funded Systems Science Research.

Project Period	Brief Project Description	Researcher	Role	Funding Source	Amount
1999–2002	Adaptive Critics for Controller Design	Lendaris	PI	NSF	$300K
2002–2003	State Space Designs for Aircraft Control	Lendaris	PI	NASA	$57K
2003–2006	Surface Design for Controllers	Lendaris	PI	NSF	$218K
2003–2006	Modeling Intracranial Pressure Dynamics in Pediatric Traumatic Brain Injury	Wakeland	co-PI	Thrasher Research Fund	$320K
2003–2006	Optimizing IV & V Costs and Benefits using Simulation	Wakeland	co-PI	NASA	$624K
2009–2011	SD Model for Reducing Risks of Prescription Drug Abuse and Diversion	Wakeland	PI	Purdue Pharma, L.P.	$198K
2011–2014	System Dynamics of Prescription Opioid Misuse	Wakeland	PI	NIH/NIDA	$360K
2014	Dynamic Model of Concussion Recovery	Wakeland	PI	Brain Trauma Foundation	$91K

Research-active faculty are sometimes able to reduce their teaching load, but due to the small size of the program, all SySc core faculty must teach at least one course per term and must advise many students, necessitating carefully balancing of priorities. The normal teaching load is four 4-credit quarter-long courses per year. It is possible for over half a faculty member's student credit hour generation to be derived from advising students regarding dissertation or thesis research, and supporting individualized readings and conference courses. These additional credit hours, however, do not (cannot) take the place of teaching regular catalog courses.

3. Results

3.1. Doctorates

As summarized in Table 3, nearly 200 Systems Science PhDs have been earned since the program's inception, specifically, 9 in the 1970's, then 27, 54, 79, and 17 in subsequent decades.

Figures 4–6 show Word diagrams that were created from the titles of dissertations awarded in the first two decades, the third decade, and the most recent decade, respectively. Several trends are visible in Figures 4–6. First, the words Systems, Analysis, Model, and Technology are prevalent in each of the figures. Business was featured in Figure 4, but was supplanted by the word Industry over time. The frequency of the words Performance, Organizational, Information, and Decision has increased over time. The word Economic was featured only in Figure 4, and the words Selection and Health were featured only in Figure 5.

Figure 4. Word Diagram of Dissertation Titles 1972 to 1993.

Figure 5. Word Diagram of Dissertation Titles 1994 to 2003.

Figure 6. Word Diagram of Dissertation Titles 2004 to 2013.

3.2. Masters Degrees

In addition, as summarized in Table 3, since 2002, over 50 MS degrees have been awarded. Most MS students have chosen the exam option, although students have recently been choosing the thesis option, with topics such as renewable energy, operational efficiency, and machine learning.

3.3. Student Placement

SySc develops the students' skills as generalists, which employers value highly as a complement to the specific skills being sought. Some of our graduates are now faculty members at PSU and several other universities, while other graduates have started companies such as consulting firms or software development firms. Many of our graduates work in governmental agencies, such as Bonneville Power, the Veterans Administration, or the National Laboratory System; and others work as researchers at public institutions and private enterprises, including healthcare, high technology, and energy consulting. Others are teaching or serving as administrators at secondary schools or community colleges. Many create their own roles in their organizations, either at the outset or over time.

4. Concluding Remarks

The evolution of PSU's Systems Science Program is continuing—SySc is now part of the PSU's School of the Environment (SoE) within the College of Liberal Arts and Sciences, and it is likely that student research topics will tend to shift towards environmental concerns and sustainability-related topics, although not to the exclusion of core systems subjects such as the development of systems methods, biomedicine, health policy, and urban systems. The move to the SoE occurred because SySc had become the only academic unit at PSU that was not located in a school or college. Several options were explored, including the Maseeh College of Engineering and Computer Science, the College of Urban and Public Affairs, and the Mathematics and Statistics department in CLAS, but the SoE proved to be the best option.

As noted earlier, many systems science programs merged over time with a specific disciplinary department, and this has tended to lead to a significant narrowing of their focus. The same could happen with SySc. However, being located in a highly interdisciplinary environmental school as opposed to a specific department should bode well for SySc, especially because systems science methods can help to strengthen the quantitative analysis capabilities of students interested in environmental science and management. As shown in Table 2, the curriculum has been evolving rapidly in recent years, and that evolution is expected to continue. In addition, despite a high degree of uncertainty in recent years, it seems reasonable to believe that the prospects for SySc remain bright, due in no small part to its ability to respond quickly to needs as they arise.

Conflicts of Interest

The author declares no conflict of interest.

References

1. Wikipedia Entry for Systems Science. Available online: http://en.wikipedia.org/wiki/Systems_science (accessed on 8 February 2014).
2. International Society for the Systems Sciences. Available online: http://isss.org/world/index.php (accessed on 8 February 2014).
3. Hawaii International Conference on Systems Sciences. Available online: http://www.hicss.hawaii.edu/ (accessed on 8 February 2014).
4. International Journal of Systems Science website. Available online: http://www.tandfonline.com/toc/tsys20/current#.UvKCw7QWmbA (accessed on 8 February 2014).
5. Mabry, P.L.; Olster, D.H.; Morgan, G.D.; Abram, D.B. Interdisciplinarity and systems science to improve population health. *Am. J. Prev. Med.* **2008**, *35*, S211–S224.
6. Sa, C.M. 'Interdisciplinary strategies' in U.S. research universities. *High Educ.* **2008**, 55, 537–552.
7. Website for a Long-Standing International Systems Institute Located in Europe: IIASA. Available online: http://en.wikipedia.org/wiki/International_Institute_for_Applied_Systems_Analysis (accessed on 8 February 2014).
8. Sante Fe Institute Website. Available online: http://www.santafe.edu/ (accessed on 8 February 2014).
9. New England Complex Systems Institute Website. Available online: http://necsi.edu/ (accessed on 8 February 2014).
10. Website for the Max Planck Institute for Dynamics and Self-Organization. Available online: http://www.ds.mpg.de/ (accessed on 8 February 2014).
11. Wikipedia Entry for Recently Established Systems Research Center Located in Australia. Available online: http://en.wikipedia.org/wiki/ARC_Centre_for_Complex_Systems (accessed on 8 February 2014).
12. Website for the Portland State University Systems Science Graduate Program. Available online: http://www.pdx.edu/sysc/ (accessed on 8 February 2014).
13. Hai, A.; Klir, G.J. An empirical investigation of reconstructability analysis: Probabilistic systems. *Int. J. Man Mach. Stud.* **1985**, *22*, 163–192.
14. Klir, G. Reconstructability analysis: An offspring of Ashby's constraint theory. *Syst. Res.* **1986**, *3*, 267–271.
15. Zwick, M. An overview of reconstructability analysis. *Kybernetes* **2004**, *33*, 877–905.
16. Haykin, S. *Neural Networks and Learning Machines*, 3rd ed.; Prentice Hall: Upper Saddle River, NJ, USA, 2009.
17. Systems Science and Industrial Engineering Programs at Binghamton University (SUNY). Available online: http://www.binghamton.edu/ssie/grad/ (accessed on 8 February 2014).
18. Ph.D. in Systems Science & Mathematics at Washington University. Available online: http://ese.wustl.edu/graduateprograms/Pages/PhDinSystemsScienceandMathematics-1.aspx (accessed on 8 February 2014).

19. Masters Degree in Systems Science at University of Ottawa. Available online: http://www.grad.uottawa.ca/Default.aspx?tabid=1727&monControl=Programmes&ProgId=607 (accessed on 8 February 2014).