Engineering and Design: Most Central Knowledge in Architecture and Engineering Jobs

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*ABSTRACT: Rapid changes in the worldwide engineering enterprise are creating a compelling rationale to rethink how future generations of engineers should be educated. In this paper, we identify the most central knowledge in engineering and architecture jobs by analyzing the characteristics of the weighted jobs–knowledge network for all occupations in the Architecture and Engineering job family of the O*NET (Occupational Information Network) system. Engineering and design constitute the most central knowledge. Strengthening education in the identified central knowledge themes can lead to better transport of knowledge to engineering jobs to address the challenges of the 21st century.*

There has been considerable discussion recently about improving engineering education ("Special Report" 2006; National Science Foundation 1995; National Academy of Sciences et al. 2010; Spinks et al. 2006; Engineers Australia 1996; National Academy of Engineering 2004; Kirschenman and Brenner 2010, 2011). This discussion stems from a widespread belief that skills and education should be improved to satisfy the demands of jobs in the current economy (Handel 2003; Bresnahan et al. 2002). A significant dimension of the rapidly emerging global economy is the "green" economy—that is, economic activity related to reducing the use of fossil fuels, decreasing pollution and greenhouse gas emissions, increasing the efficiency of energy use, recycling materials, and developing and adopting renewable sources of energy. Considerable debate has revolved around envisioning the future and responding to these global challenges (Liao 2008 and references therein).

To study the changing world of work, the National Center for O*NET Development (O*NET is the Occupational Information Network, an online service developed for the U.S. Department of Labor; see O*NET n.d.) investigated the impact of green economy activities and technologies on occupational requirements and the development of new and emerging (N&E) occupations (Dierdorff et al. 2009). Results of the O*NET research led to the identification of green economic sectors, green increased demand occupations, green enhanced skills occupations, and green N&E occupations (National Center for O*NET Development 2009). The engineering job family (Architecture and Engineering) comprises more than one-fifth (13 occupations) of the green enhanced skills occupations and almost one-third (28 occupations) of the total green N&E occupations (Neofotistos and Asteris 2010).

To contribute to the development of an efficient green jobs engineering pipeline that is flexible enough to support diverse career aspirations and a broad range of concerns, we sought to identify the most central knowledge in the existing Architecture and Engineering job family in the O*NET database. Our approach was inspired by recent advances in network theory suggesting that transport in networks can be

Table 1. List of O*NET Knowledge Categories

No.	Category
1	Administration and Management
2	Biology
3	Building and Construction
4	Chemistry
5	Clerical
6	Communications and Media
7	Computers and Electronics
8	Customer and Personal Service
9	Design
10	Economics and Accounting
11	Education and Training
12	Engineering and Technology
13	English Language
14	Fine Arts
15	Food Production
16	Foreign Language
17	Geography
18	History and Archeology
19	Law and Government
20	Mathematics
21	Mechanical
22	Medicine and Dentistry
23	Personnel and Human Resources
24	Philosophy and Theology
25	Physics
26	Production and Processing
27	Psychology
28	Public Safety and Security
29	Sales and Marketing
30	Sociology and Anthropology
31	Telecommunications
32	Therapy and Counseling
33	Transportation

Table 2. List of Jobs in the O*NET Architecture and Engineering Job Family

No.	Job
1	Aerospace Engineering and Operations Technicians
2	Aerospace Engineers
3	Agricultural Engineers
4	Architects, except Landscape and Naval
5	Architectural Drafters
6	Biomedical Engineers
7	Cartographers and Photogrammetrists
8	Chemical Engineers
9	Civil Drafters
10	Civil Engineering Technicians
11	Civil Engineers
12	Computer Hardware Engineers
13	Electrical Drafters
14	Electrical Engineering Technicians
15	Electrical Engineers
16	Electro-Mechanical Technicians
17	Electronic Drafters
18	Electronics Engineering Technicians
19	Electronics Engineers, Except Computer
20	Environmental Engineering Technicians
21	Environmental Engineers
22	Fire-Prevention and Protection Engineers
23	Industrial Engineering Technicians
24	Industrial Engineers
25	Industrial Safety and Health Engineers
26	Landscape Architects
27	Mapping Technicians
28	Marine Architects
29	Marine Engineers
30	Materials Engineers
31	Mechanical Drafters
32	Mechanical Engineering Technicians
33	Mechanical Engineers
34	Mining and Geological Engineers, including Mining Safety Engineers
35	Nuclear Engineers
36	Petroleum Engineers
37	Product Safety Engineers
38	Surveying Technicians
39	Surveyors

significantly enhanced by improving the high-centrality nodes (Wu et al. 2006). Thus, strengthening the central knowledge can lead to better transport of knowledge to the engineering and architecture jobs in the contemporary world.

O*NET Database

O*NET is an online service developed for (but not by) the U.S. Department of Labor (as the successor to the better-known *Dictionary of Occupational Titles*) containing information on U.S. occupations

Table 3. Weights of the Links between Knowledge and Selected Jobs Comprising the O*NET Architecture and Engineering Job Family

	Job Weight				
Knowledge	Architects	Civil engineers	Electrical engineers	Industrial engineers	Mechanical engineers
Administration and Management	66	63	43	67	70
Biology	18	28	10	18	2
Building and Construction	97	94	21	29	25
Chemistry	23	53	43	28	33
Clerical	50	42	38	56	21
Communications and Media	44	36	26	23	27
Computers and Electronics	65	56	86	64	53
Customer and Personal Service	62	60	48	50	43
Design	94	95	73	62	75
Economics and Accounting	43	44	20	50	13
Education and Training	42	42	38	57	29
Engineering and Technology	72	98	98	88	88
English Language	67	78	76	57	55
Fine Arts	38	5	5	9	0
Food Production	2	7	1	9	4
Foreign Language	4	14	9	16	1
Geography	33	47	16	17	5
History and Archeology	32	18	5	9	0
Law and Government	57	56	15	34	15
Mathematics	66	88	78	84	72
Mechanical	49	39	42	65	78
Medicine and Dentistry	4	6	6	8	2
Personnel and Human Resources	34	48	20	38	12
Philosophy and Theology	14	13	6	8	2
Physics	40	73	70	43	50
Production and Processing	38	31	53	86	73
Psychology	30	26	41	34	11
Public Safety and Security	59	60	33	36	33
Sales and Marketing	50	41	28	23	32
Sociology and Anthropology	19	11	19	27	3
Telecommunications	35	25	54	26	7
Therapy and Counseling	3	8	9	18	1
Transportation	18	68	22	34	13

that correspond to the Labor Department's Standard Occupational Classification (SOC). The O*NET database contains information on standardized and occupation-specific descriptors and is continually updated via a survey of a broad range of workers from each occupation. The O*NET—SOC 2006 taxonomy included 949 occupational titles, 812 of which represent data-level occupations.

In June 2009, the release of the O*NET 14.0 database (O*NET—SOC 2009) updated the taxonomy to include 1,102 occupational titles, 965 of which represent O*NET data-level occupations. Regarding the impact of the green economy, O*NET created three general occupational categories, each describing different consequences of green economy activities and technologies for occupational performance (Dierdorff et al. 2009; National Center for O*NET Development 2009):

1. *Green increased demand occupations* (64 occupations)—Employment demand has increased for an existing occupation (but this impact does not entail significant changes in the work and worker requirements of the occupation—the work context may change, but the tasks themselves do not);
2. *Green enhanced skills occupations* (60 occupations)—The work and worker requirements of an existing O*NET—SOC occupation have changed significantly (but the impact may or may not result in an increase in employment demand for the occupation—the essential purposes of the occupation remain the same, but tasks, skills, knowledge, and external elements, such as credentials, have been altered); and
3. *Green new and emerging occupations* (91 occupations)—A need for unique work and worker requirements has been created, resulting in the generation of a new occupation in the O*NET taxonomy (this new occupation could be entirely novel or born of an existing occupation).

Methodological Approach and Results

We undertook to identify the most central knowledge in the Architecture and Engineering job family of the O*NET database, in which each job is characterized by a weight in each one of the 33 knowledge categories (Table 1). The Architecture and Engineering job family consists of 39 jobs (Table 2); Table 3 presents the weights of selected engineering jobs.

We applied methods of network analysis to reveal the most central knowledge by identifying the maximum spanning tree (MST) in the jobs–knowledge network and ranking the centrality of its nodes. We treated the network as a monopartite network (however, the results remain the same by treating the network as a bipartite weighted network; this part of our work will be presented in a companion paper). In particular, we ascertained the most central knowledge by identifying the MST in the network. The MST is the tree connecting all nodes with the maximum total weight and dominates transport in weighted networks. The MST is obtained from the weighted network using Prim's algorithm.

Table 4. Ranking of the Most Central Knowledge Domains in the Jobs–Knowledge Network of the O*NET Architecture and Engineering Job Family

Architecture and Engineering occupations	Degree centrality
Engineering and Technology	20
Design	9
Computers and Electronics	6
Mathematics	4
Production and Processing	2
Law and Government	2
Geography	2

Note: Ranks are in descending order by the total sum of nonzero maximum spanning tree degree centralities.

In large, complex networks, not all nodes are equivalent (Wu et al. 2006; Braunstein et al. 2007). The degree centrality ranking addresses the question, Which is the most important or central node in this network? The simplest of centrality measures is degree centrality, also called *simply degree*. The degree of a node in a network is the number of links attached to it. We view the jobs–knowledge network in terms of its transport properties—that is, the ease with which knowledge is linked to engineering jobs. Links with greater weights can be interpreted as more important ("wider") roads in connecting the nodes, and nodes with higher centrality are more important in spanning the network. From this perspective, transport in the aforementioned weighted network is dominated by the MST.

Once we identified the MST, we ranked the degree centrality of its nodes; the results are presented in Table 4. The most central knowledge categories are Engineering and Technology, Design, Computers and Electronics, Mathematics, Production and Processing, Law and Government, and Geography. Indeed, considerable effort is currently being directed at improving these central engineering knowledge areas (Kirschenman and Brenner 2011; ASCE 2008).

Conclusion

This paper describes the results of our applied network analysis of the most central knowledge in the Architecture and Engineering job family in the O*NET database. The two areas of most central knowledge we identified—(1) Engineering and Technology and (2) Design—validate efforts such as those of the ASCE Body of Knowledge (BOK) committees to change the way the civil engineering curriculum is presented. They also suggest use of a series of project-based design courses as a central core theme (Kirschenman and Brenner 2010, 2011) for the 5-year education period proposed in the BOK-2 document (ASCE 2008). These efforts should be strongly considered as extending beyond the boundaries of the civil engineering field. Our findings contribute to the ongoing discourse on how future generations of scientists, engineers, managers, and other professionals should be educated and constitute a first step toward the development of a more efficient engineering pipeline leading to a better integrated educational framework that is flexible enough to support diverse career aspirations and a broad range of concerns.

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