AC 2011-289: WHAT IS STEM?

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1. Introduction

STEM in the U.S.

The shortage US students and workers in high technology fields has made STEM education a high priority topic for education research[1]. The United States continues to fall in categories of STEM education. In 2007, the United States ranked 21st out of 30 Organization for Economic Co-operation and Development (OECD) countries in science, and ranked 25th in mathematics[2]. These losses are not just in absolute numbers. In 2003, there were 104.35 engineering degrees per one-thousand 24-year old persons in Taiwan, 27.33 in the United Kingdom, but only 19.48 in the United States[3].

Concern over this has risen to the highest ranks of government, with President Obama declaring that the country had slipped from the top position it once held in the field of innovation and advanced technology worldwide[4]. In the 20th century, numerous new technologies, products, and innovations were invented in the U.S., described by many as miraculous. President Obama has stated the goal for science and math education is to reach the top position worldwide in the next decade. As an innovation leader, the U.S. economy has seen rapid growth in part, because of the solid technological support. Those critical disciplines have more influence on economic development when compared to other non-STEM fields[5]. A basic STEM education is critical for most of the technical, engineering and even management related jobs[6]. STEM education is the main source of scientists, engineers, and workers with technological skills[6].

Problem Statement: What is STEM?

Judith A. Ramaley, the former director of the National Science Foundation's Education and Human Resources Division is credited with defining the science, technology, engineering, and mathematics curriculum as STEM[7]. Soon after, various professional and educational institutes then began to realize the importance of STEM education and the declining levels of education for U.S. students in STEM fields. At its simplest, the term STEM stands for the four primary discipline families of Science, Technology, Engineering and Mathematics. However, many organizations, institutes, and researchers do not have a clear classification of the specific disciplines that comprise STEM. More problematic is differing definitions that include or exclude large fields like health sciences and agriculture.

The problem is that research institutes, government organizations and occupational groups, as well as different groups involved in STEM use different definitions of STEM, based on their perspectives. Therefore, providing a clear and consistent definition and classification of STEM fields is necessary, not only for research, but also for measuring and improving STEM education in the U.S. Without a consistent definition, analyses between organizations may not reconcile and meta-analysis may be infeasible.

The purpose of research is to determine a consistent definition and classification for STEM disciplines by studying the various definitions of STEM used by the institutions, organizations, universities and researchers concerned with STEM. This classification scheme is based on the disciplines which are almost always included in STEM (e.g. Civil Engineering), disciplines which are sometimes in STEM (e.g. Database Administrators), and disciplines which are seldom found in STEM definitions (e.g. Political Scientists). Then, to explain the reasons why some logical STEM disciplines may not be frequently defined as such, or why expected non-STEM disciplines are included are in some definitions. Hypothesis tests are not applied in this paper, as it is a STEM definition survey collection. The second purpose of this work is to map the coding for STEM disciplines into both education and occupational codes.

2. Background

In this paper, definitions for STEM fall into one of two domains: education or occupation. The specific discipline categories used in the education domain are derived from the National Center for Education Statistics Classification of Instructional Programs 2000[8] and the Classification of Instructional Programs 1990[9]. The standard Occupational Classification (SOC) system is used in the occupational domain.

CIP and CIP Codes

The National Center for Education Statistics (NCES), of the U. S. Department of Education, developed the Classification of Instructional Programs (CIP). CIP includes all the disciplines offered in academic institutions and universities in the United States. For each discipline, there is a specific CIP code. However, CIP is a 3-level, hierarchical system, with each level defining more specific disciplines. CIP codes can therefore be two-digit, four-digit or six-digit, depending on the level of specification.

CIP codes were introduced in 1980, and were later revised in 1985, 1990 and 2000. The newest edition is the 2010. In each edition, some disciplines are eliminated, some are added, and some codes or names are changed[8]. To address this inconsistency, NCES provides a crosswalk for CIP code versions.

SOC and SOC Codes

The Standard Occupational Classification (SOC) system is used by the U.S. government for non-profit purposes. SOC classifies occupational titles into four levels: major level; minor group; broad occupation; and detailed occupation. It includes 860 detailed occupations, which are classified into 23 major groups. Each of the 23 major groups includes numerical middle level occupations[10]. The 2000 SOC codes are defined by the federal government, and it is the effort of all the federal agencies who are using this data[10]. The 2010 SOC codes are the newest edition available. There is also a crosswalk between 2000 and 2010.

3. Methodology

STEM Definitions Collection

In this research, papers, conference reports, websites for programs, government documents and other statistical data were collected and mapped into the appropriate discipline coding scheme. For educational definitions of STEM, the CIP 6-digit codes for the year 2000 are used. For definitions that proscribe occupational STEM disciplines, the 2000 SOC codes are used. In cases where the definition is not to the lowest level of the coding scheme, the lowest level appropriate is identified and all sub-categories are coded.

The sources for STEM are mapped into the appropriate CIP or SOC codes. For each definition, a discipline is designated as “1” if it is defined as a STEM fields in the source, and is coded as “0” if it is explicitly defined as a non-STEM field. It will be blank (null) if it cannot be classified.

4. Data

It was quickly seen that some sources defined specific disciplines in their classification and some only defined higher discipline families, omitting detailed disciplines. And, some sources only defined the non-STEM fields. In CIP coding, 40 distinct STEM definitions from universities, government organizations, papers and books in the field were collected and all of the listed disciplines are mapped into the 2000 CIP codes. For the more than 1000 disciplines, it uses the CIP 2000 codes. However some stated disciplines are not listed in the CIP 2000 codes, but they are mentioned in the definitions, the discipline names with CIP 1990 or CIP 2010 codes were listed as appropriate.

In occupations, 11 sources were collected. The sources include the Employment and Training Administration O*NET Online occupations list, the economist Nicholas Terrell, the Flint Group Occupations, STEM Extracts from the National Employment Matrix, the Current Population Survey from the BLS, the Commission on Professionals in Science and Technology (CPST), NSF/Division of Science Resources Statistics, Survey of Earned Doctorates 2008, NSF/Division of Science Resources Statistics-Science and engineering indicators 2010, SMART Scholarship and others. Most of the sources are non-profit organizations.

Classification for STEM Education

For each discipline, the probability of it being defined as a STEM field is calculated by formula 1.

$$p = \frac{n_i - n_e}{N} \qquad (1)$$

Where,

n_i = number of definitions where the discipline is included
n_e = number of definitions where the discipline is explicitly excluded
N = the total number of definitions

The histogram in figure 1 shows the numbers of disciplines with associated probabilities. There are 846 disciplines with probabilities under 5% excluded from the figure.

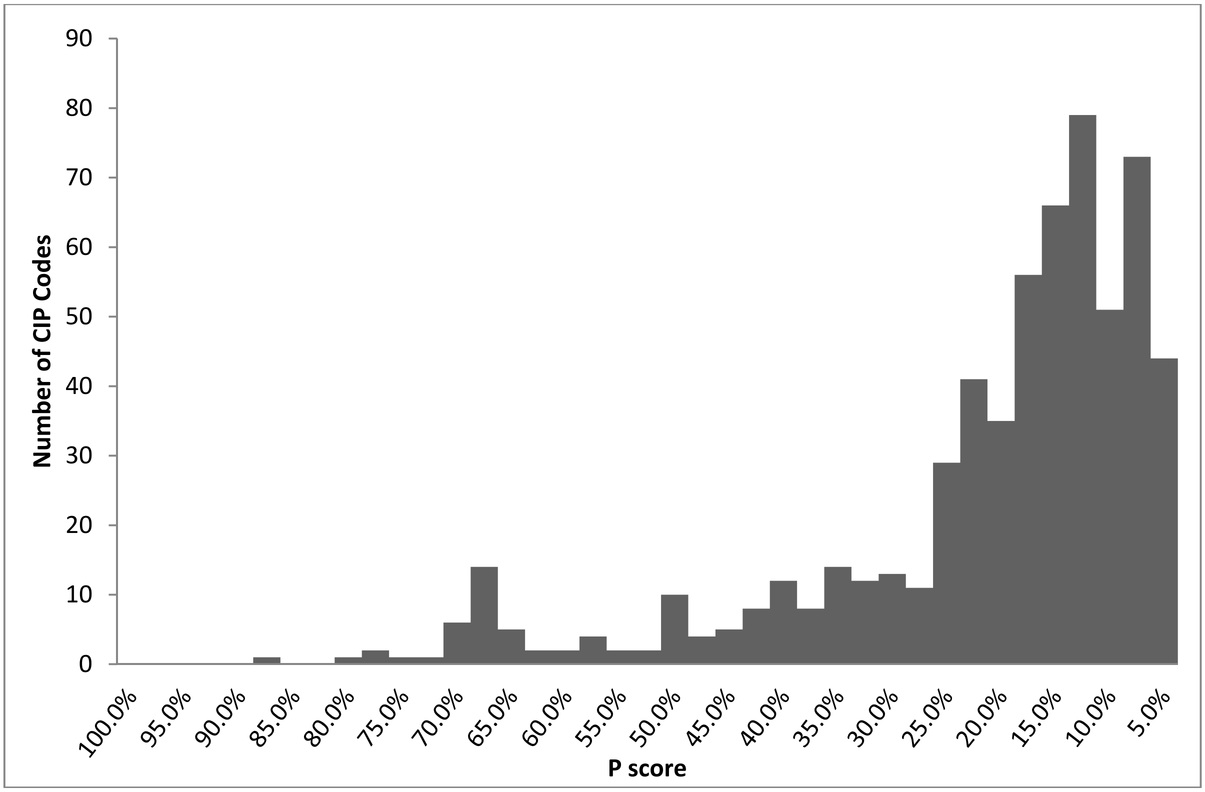

Figure 1. Educational STEM Disciplines Distribution.

The histogram shows quite a bit of variation. One crest occurs around 65%. A second crest can be seen around 35.0%. A third crest is around 15.0%. In this work, the codes at or above 60% were designated as high-frequency STEM. Those from 25% to 55% were designated as medium-frequency STEM and those below 25% were termed low-frequency STEM. Table 1 presents all of the high-frequency STEM disciplines based on the educational dimension definitions.

Table 1 High-frequency STEM Education Fields

P Score	Programs (CIP 2000 Code)
0.875	Mathematics, General (27.0101)
0.8	Chemistry, General (40.0501)
0.775	Computer Science (11.0701), Biology/Biological Sciences, General (26.0101)
0.75	Physics, General (40.0801)
0.725	Mathematics, Other (27.0199)
0.7	Mathematics (27.01), Algebra and Number Theory (27.0102), Organic Chemistry (40.0504), Physical and Theoretical Chemistry (40.0506), Polymer Chemistry (40.0507), Nuclear Physics (40.0806)

P Score	Programs (CIP 2000 Code)
0.675	Analysis and Functional Analysis (27.0103), Geometry/Geometric Analysis (27.0104), Topology and Foundations (27.0105), Analytical Chemistry (40.0502), Inorganic Chemistry (40.0503), Chemical Physics (40.0508), Geology/Earth Science, General (40.0601), Atomic/Molecular Physics (40.0802), Elementary Particle Physics (40.0804), Plasma and High-Temperature Physics (40.0805), Optics/Optical Sciences (40.0807), Solid State and Low-Temperature Physics (40.0808), Theoretical and Mathematical Physics (40.081), Acoustics (40.0809)
0.65	Computer Science (11.07), Civil Engineering, General (14.0801), Electrical, Electronics and Communications Engineering (14.1001), Mechanical Engineering (14.1901), Chemistry, Other (40.0599)
0.625	Physics, Other (40.0899), Chemistry (40.05)
0.6	Chemical Engineering (14.0701), Physics (40.08)

Classification for STEM Occupation

Fewer definitions for STEM in occupation exist; 11 sources were collected and most of the sources are again non-profit organizations. There are a total of 860 detailed SOC titles in the 2000 SOC system and the 2010 SOC system.

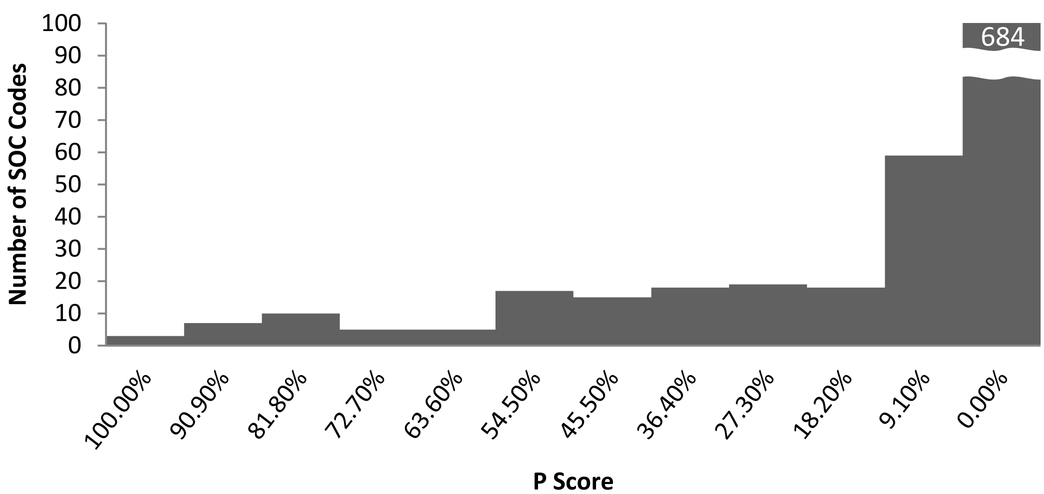

Figure 2. Occupational STEM Disciplines Distribution.

For each discipline, the same formula was applied as for the educational dimension, which is provided as formula 1. Figure 2 shows the probability distribution for those disciplines. In this figure, there is one crest around 81.80%, and two minimal troughs. Between 54.50% and 18.20%, it is almost constant, which is much higher than the crest (~81.80%). From 9.10%, it increases dramatically. Therefore, the disciplines with probabilities between 100% and 63.6% are defined as high-frequency STEM fields; the disciplines with probabilities between 54.5% and 18.2% are defined as medium-frequency STEM fields; and the disciplines with probabilities

9.1% are defined as low-frequency STEM fields. Table 2 lists the high-frequency SOC codes in the analysis.

Table 2 High-frequency STEM Occupation Fields

P Score	Programs (SOC 2000 Code)
0.917	Chemical Engineers (17-2041), Civil Engineers (17-2051), Materials Engineers (17-2131), Aerospace Engineers (17-2011), Agricultural Engineers (17-2021), Electrical Engineers (17-2071), Industrial Engineers (17-2112), Marine Engineers and Naval Architects (17-2121), Mechanical Engineers (17-2141), Nuclear Engineers (17-2161), Computer Software Engineers, Applications (15-1031), Computer Software Engineers, Systems Software (15-1032), Biomedical Engineers (17-2031), Computer Hardware Engineers (17-2061), Electronics Engineers, Except Computer (17-2072), Environmental Engineers (17-2081), Mining and Geological Engineers, Including Mining Safety Engineers (17-2151), Petroleum Engineers (17-2171), Biological Scientists, All Other (19-1029), Physicists (19-2012)
0.727	Mathematicians (15-2021), Engineers, All Other (17-2199), Chemists (19-2031), Physical Scientists, All Other (19-2099), Agricultural and Food Science Technicians (19-4011)
0.636	Statisticians (15-2041), Health and Safety Engineers, Except Mining Safety Engineers and Inspectors (17-2111), Astronomers (19-2011), Atmospheric and Space Scientists (19-2021), Sales Engineers (41-9031)

5. Conclusions

Medium-Frequency STEM

The medium-frequency STEM is where the contention lies. In educational disciplines the next most frequent disciplines, after the high-frequency are: Geotechnical Engineering, Structural Engineering, Transportation and Highway Engineering and Water Resources Engineering. These would all seem to be STEM. Their omission from the high-frequency category lies in the granularity of definition of the STEM definitions. These are specialized fields of engineering and are often not explicitly declared; only receiving votes when a parent CIP code is specified. In some definitions, the specific disciplines, like Civil Engineering were specified, eliminating the hierarchical path to the code. Similar discrepancies exist in the SOC codes. This may occur because an institution defines only the CIP codes for programs they have, omitting programs which would likely have been categorized as STEM if they offered or oversaw them.

Low-Frequency STEM

The disciplines in low-frequency STEM are also complicated. For example, Animal Science, Anatomy and Nursing all appear in low-frequency. They do not fall into the hierarchical complication of some of the medium-frequency codes. Their low scores result from the organizations defining STEM. Many of the agriculture disciplines are not defined as STEM because the organization making the definition does not invest in, oversee or have an agricultural component. One common definition, from NSF, which tracks science and engineering degrees, does not include agriculture[11]. Presumably, the Department of Agriculture is more concerned with those educational disciplines. Likewise, the National Institutes of Health is focused on health disciplines in education. These institutions are more focused and may not promote a broad STEM definition.

Comparison between STEM Education and STEM Occupation

The data in section 4 shows that the STEM definitions used by educational organizations are different from organizations focused on occupations. High-frequency STEM fields derived from educational organization definitions are mathematics, chemistry, computer science, biological sciences, physics, geometric analysis, and engineering disciplines related to computer science, electrical, chemical and mechanical engineering. These fields are more heavily focused on the mathematics and science fields.

Occupational definitions showed that high-frequency STEM occupations include sophisticated technology or science related engineers, biological scientists, physicists, mathematicians, chemists, astronomy related scientists, food related technicians. It focuses more on the practical and applicable job titles, such as chemical engineer, civil engineer, materials engineers, and electrical engineers. The natural sciences related disciplines also have a high frequency of being defined as STEM fields.

For the different definitions in educational and occupations world, the reason is the different perspectives in the two different groups. Educational organization definitions are from scholars' research, universities' programs, reports from NSF, and other research institutes. They focus more on the theory study and research, for which the mathematics, natural sciences, and computer science are the foundation. However, the definitions for STEM occupations are from the Employment and Training Administration-O*NET Online occupations, Flint Group Occupations, statistical survey data from the Bureau of Labor Statistics, and other occupation statistics related organizations. Their focus is on the data collection for all job titles. Therefore, as the most common job titles, all kinds of technology related engineers are defined as STEM with a high frequency, and the practical, science related scientists and mathematicians are considered as STEM more frequently. Food and agriculture related technicians are defined as STEM frequently, because it is a very practical and normal job title in the real job market. However, there may not be many scholars or universities doing research in food technologies.

Ramifications

The ramification of this mismatch is that universities and institutions which focus on education have a focus on STEM which differs from those of organizations focusing on workforce needs. This disconnect likely leads to an emphasis on career development which does not match the intent of developing a STEM workforce. The fragmented approach to defining STEM in an ad hoc manner to suit the needs of a specific organization should be countered with a unified definition of STEM that best suits the needs of the country.

Limitations

The limitation in this work is that there are a limited number of definitions and most do not provide full documentation of the fields included in their definition. Also, a number of documents may need to be referred to determine a single organization's definition, and it is only possible to determine whether they include a specific discipline in STEM. Another limitation is that most of the organizations only provide the higher level disciplines in the STEM definition, such as "agriculture sciences", the discipline name "agriculture science" does not exist in the CIP code, but 74 specific disciplines are listed related with agriculture sciences field.

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