Ergonomics Topics for the Undergraduate Classroom

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Abstract

The industrial engineering classroom must continually evolve to meet the needs of a changing workplace. In the undergraduate education of an industrial engineer, the core curriculum is packed with broad topics including engineering economy, statistics, operations research and manufacturing systems. Most industrial engineering programs will include a course or a series of courses in work design and/or ergonomics, although the content coverage will likely vary depending on the term length, instructor preference and institutional focus. The introductory course may scratch the surface of a variety of topics or provide an in-depth look at a focused group of topics.

The purpose of this paper is to analyze the topics taught in traditional ergonomics courses. With the understanding that undergraduate ergonomic courses should align with professional societies as well as industrial needs, the courses and labs are compared to professional standards of well-respected industrial and academic organizations. In addition, ongoing discussions with external industrial constituents validate the importance of contemporary topics to prepare students to enter the workforce.

This information can be used to assess core competencies and appropriate performance criteria to improve course content and delivery. Two courses will be contrasted based on their syllabus topics with future applications to learning objectives, lab resources, and teaching strategies.

I. Introduction

The topic of ergonomics is typically taught within the undergraduate Industrial Engineering (IE) program. Introductory courses often introduce both theory and practice while,

- offering theoretical coverage of topics such as human cognition and biomechanics,
- making use of industrial applications,
- assigning real-world design problems and
- promoting experiential learning in laboratory settings.

The multi-disciplinary nature of ergonomics and its broad application in many domains (e.g., transportation, manufacturing, aviation, medicine, product design, software development) means that potential course topics are numerous and therefore the instructor usually has much latitude in designing course coverage and types of assignments.

In practice, the broad range of topics within ergonomics can be included in a variety of IE undergraduate courses. Typical course names include Ergonomics, Human Factors, Methods Engineering, Safety Engineering, Cognitive Engineering and Work Design, among others.[6] In a 2015 review of the 94 ABET accredited IE programs, Jane Fraser[7] states that 90% of those programs require work methods, human factors or ergonomics. Fraser's 121 credit hour "generic" plan of study, which she feels describes most IE programs, includes two related courses: three credit hours of "work methods" and three credit hours of "human factors." Some portion of these IE programs require only one three-credit-hour course that covers both work methods and human factors topics. IE programs may also offer advanced topics in ergonomics that are available as electives to undergraduate students. There is also a subset of IE undergraduate programs that have no required courses in these areas; Fraser's numbers indicate that this is only about 10% of ABET accredited IE programs.

Under the premise that ergonomics is an important subject in an undergraduate IE education, the initial goal of this paper is to determine if there is a standard set of topics that should be included in a one-semester ergonomics course. We look for guidance from professional organizations such as the National Council of Examiners for Engineering and Surveying (NCEES), the International Ergonomics Association (IEA), the Human Factors and Ergonomics Society (HFES) and the Board of Certification in Professional Ergonomics (BCPE). We also examine the results of a recent survey of ABET accredited IE programs, and make a side-by-side comparison of the topics included in our own ergonomics courses.

Staying relevant and up-to-date in the teaching of fundamental principles is essential in higher education. In the ergonomics classroom it is particularly important to monitor industry trends and workforce changes as they relate to the design of the workplace. The second goal of this paper is therefore to examine evolving needs of industry in the area of ergonomics. For example, has the increase in automation and robotics in the manufacturing environment shifted the educational needs of our graduates, and therefore what we should be teaching in the classroom? Do the needs for ergonomics vary from one industry to another? To answer these questions, we examine contemporary ergonomic topics in various industries, talk to industry experts, and compare these contemporary topics to the curricular guidance given us by professional groups such as NCEES and HFES. Our final goal is then to answer the expanded question "What should be included in a required ergonomics course at the undergraduate level in order to prepare our IE graduates for a changing workplace?"

II. What is Ergonomics?

The terms Ergonomics, Human Factors and Human Factors Engineering are often considered to be synonymous.[11] The definitions of these terms vary somewhat among professional societies, the scientific literature, government agencies and industry, and a summary of the definitions can be found on the Human Factors and Ergonomics Society website.[9] The definition for Ergonomics developed by the International Ergonomics Association[10] is commonly accepted:

> *Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.*

Professional organizations can also provide insight into what defines the field of ergonomics by identifying the topics that they feel are intrinsic to the field. A focused look at course topics compared to professional organization websites allows a comparison of the similarities and differences that exist between the many constituents with an interest in ergonomics.

The National Council of Examiners for Engineering and Surveying (NCEES) develops and administers exams used for engineering and surveying licensure in the U.S.[12] The Fundamentals of Engineering (FE) Exam is the first step toward becoming a Professional Engineer, and therefore the body of knowledge covered by the industrial engineering exam is very relevant to the topics we teach in our undergraduate programs. The FE Exam is a six-hour exam which contains 110 multiple-choice questions. The following list of 13 knowledge categories (cite NCEES website) defines the body of knowledge for the IE version of the FE Exam. This list shows the number of questions expected from each category and the subtopics associated with only Category 10, Human Factors, Ergonomics and Safety. Category 10 has the most relevance to an ergonomics course, although as discussed earlier, some IE programs may combine topics from Categories 10 and 11 in one course. There are 8-12 exam questions drawn from Category 10 (7-11% of the FE Exam). The relationship between this list of topics and IE curricular content will be further discussed in the next section of this paper.

1. Mathematics: 6–9 questions
2. Engineering Sciences: 5–8 questions
3. Ethics and Professional Practice: 5–8 questions
4. Engineering Economics: 10–15 questions
5. Probability and Statistics: 10–15 questions
6. Modeling and Computations: 8–12 questions
7. Industrial Management: 8–12 questions
8. Manufacturing, Production, and Service Systems: 8–12 questions
9. Facilities and Logistics: 8–12 questions
10. Human Factors, Ergonomics, and Safety: 8–12 questions
    - A. Hazard identification and risk assessment
    - B. Environmental stress assessment (e.g., noise, vibrations, heat)
    - C. Industrial hygiene
    - D. Design for usability (e.g., tasks, tools, displays, controls, user interfaces)
    - E. Anthropometry
    - F. Biomechanics
    - G. Cumulative trauma disorders (e.g., low back injuries, carpal tunnel syndrome)
    - H. Systems safety
    - I. Cognitive engineering (e.g., information processing, situation awareness, human error, mental models)
11. Work Design: 8–12 questions
12. Quality: 8–12 questions
13. Systems Engineering: 8–12 questions

Ergonomics is a multidisciplinary field, and therefore cannot be adequately defined without moving outside of engineering colleges and engineering licensing exams. Undergraduate and graduate courses (and degrees) are offered in colleges of engineering, usually in industrial engineering departments, but are also commonly offered in psychology departments. The Human Factors and Ergonomics Society (HFES) has been accrediting graduate human factors and ergonomics programs since the late 1990s. The HFES website[8] currently lists 17 accredited graduate programs, of which ten are housed in psychology departments, six are housed in industrial engineering or industrial and systems engineering (ISE) departments, and one university (San Jose State University) has a joint program between the ISE, psychology, industrial design and kinesiology departments.

The HFES website also lists 56 other graduate programs in human factors/ergonomics which have not been accredited by HFES.[8] Some programs describe an emphasis within a particular degree, such as an MSIE or MS or Ph.D. in Psychology; while others advertise a graduate degree focused solely on ergonomics or human factors. Of these 56 programs on the HFES website, 24 are from engineering colleges, 18 are from psychology departments and 14 are from what we have categorized as "other" departments, e.g., health sciences, environmental sciences, information design, aviation, cognitive learning and human factors.

While our interest lies in defining the content of an introductory ergonomics course for IE undergraduates, we find that the HFES Accreditation Guide[8] provides valuable information. First, it acknowledges that the field of human factors/ergonomics is broad and their expectation is that graduate programs will vary considerably. They also define what they feel should be common to all programs, i.e., the core competencies that provide a general background in human factors/ergonomics. This is what we seek to define for our own undergraduate ergonomics courses. Figure 1 shows the three core areas defined by HFES. Of most interest to our purpose, is their requirement that each program should have a three-credit course that provides a survey of the field. This survey course must contain at least seven of the areas listed under Core Area #1. We compare this list of topics in Core Area 1 to the list of ergonomics topics from the FE Exam.

CORE AREA 1. An Understanding of Human Capabilities and Limitations

- ❑ Information processing
- ❑ Biomechanics
- ❑ Perception and action
- ❑ Ecological psychology
- ❑ Anthropometry
- ❑ Kinesiology
- ❑ Neuropsychology
- ❑ Cognitive science
- ❑ Communication
- ❑ Sociology
- ❑ Anthropology
- ❑ Physiological Psychology
- ❑ Organizational Psychology
- ❑ Naturalistic decision making
- ❑ Human performance
- ❑ Social Psychology
- ❑ Situated cognition
- ❑ Macroergonomics
- ❑ Joint action
- ❑ Physiology
- ❑ Industrial/Workplace Ergonomics
- ❑ Human Systems Integration
- ❑ Human Error
- ❑ Environmental Effects
- ❑ **Other** (to be approved by accreditation committee)

CORE AREA 2. Skills in Carrying Out Evidence-Based HF/E Methods

- ❑ Cognitive task analysis
- ❑ Task analysis
- ❑ Knowledge elicitation/acquisition
- ❑ Experimental design
- ❑ Industrial design
- ❑ Computational modeling
- ❑ Dynamical Systems modeling
- ❑ Mathematical modeling
- ❑ Experimental Statistics
- ❑ Prototyping
- ❑ Simulation
- ❑ Usability Testing
- ❑ Neuroergonomics
- ❑ Discrete event simulation
- ❑ Reliability
- ❑ Control Theory
- **Other** (to be approved by accreditation committee)

CORE AREA 3. Knowledge of Application Domains in the Field of HF/E

- ❑ Environmental design
- ❑ Cognitive Engineering
- ❑ Expert Systems
- ❑ Human-Computer Interaction
- ❑ Safety
- ❑ Inspection
- ❑ Human Systems Integration
- ❑ Displays
- ❑ Controls
- ❑ Transportation
- ❑ Aviation
- ❑ Training and assessment
- ❑ Augmented cognition
- ❑ Medicine
- ❑ Energy
- ❑ Disaster Response
- ❑ Industrial Ergonomics
- ❑ System/Product design
- ❑ Workstation Design
- ❑ Tools
- ❑ **Other** (to be approved by accreditation committee)

Figure 1. Core Areas in Curriculum Requirements for HFES Accreditation of Human Factors and Ergonomics Graduate Programs[8]

Table 1 provides a cross reference of ergonomics topics from Category 10 of the FE Exam and selected topics included in the HFES Core Area 1. The mapping is obvious in some cases because of common terminology (e.g., anthropometry and biomechanics), and in others some judgement was used on our part. We felt that the 9 FE Exam topics could be mapped to 9 of the 24 topics in Core Area 1. Therefore an undergraduate ergonomics course conforming to the IE Body of Knowledge defined by NCEES would qualify as a survey course of ergonomics, as defined by HFES. It is quite reasonable that the HFES list is much longer than the FE Exam list, as they are looking at programs outside of engineering and much broader topic areas.

Table 1. Comparison of the FE Exam Ergonomics Topics with HFES Core Area 1 Topics

FE Exam Ergonomics Topics	HFES Core Area 1 Topics
A. Hazard identification and risk assessment*	
B. Environmental stress assessment (e.g., noise, vibrations, heat)	Environmental Effects
C. Industrial hygiene	
D. Design for usability (e.g., tasks, tools, displays, controls, user interfaces)	Industrial/Workplace Ergonomics**
E. Anthropometry	Anthropometry
F. Biomechanics	Biomechanics
G. Cumulative trauma disorders (e.g., low back injuries, carpal tunnel syndrome)	Physiology Industrial/Workplace Ergonomics**
H. Systems safety	
I. Cognitive engineering (e.g., information processing, situation awareness, human error, mental models)	Cognitive science Information processing Perception and action Human Error

*Core Area 3 includes safety, inspection, and training & assessment
**Industrial/Workplace Ergonomics overlaps with topics D and G.

While NCEES is concerned with licensure of degreed engineers, the Board of Certification in Professional Ergonomics (BCPE), provides certification for practitioners of human factors/ergonomics.[2] Professional certification requirements (e.g., Certified Professional Ergonomist, CPE) include course work, work experience and a passing score on the certification exam. The course work and exam content is based on core competencies in the areas of Analysis, Design, Validation and Implementation. While is there clearly overlap between these core competencies, the core areas from HFES accreditation requirements, and the topics from the FE Exam, it is difficult to draw parallels or provide a clear framework for comparison.

III. Ergonomics Topics Taught in IE Undergraduate Programs

Both authors of this paper teach undergraduate ergonomics courses at their respective universities. Comparison of teaching pedagogy and sharing of teaching materials lead to interest in the topic of this paper, and in particular, the answer to the question, what should be the content of an introductory ergonomics class for IE undergraduates? This section compares the content of our two classes to each other and against the FE Exam Specifications. We also report some interesting results from a recent survey sponsored by the NCEES PE Exam Committee, the FE Exam Committee and the Council of Industrial Engineering Academic Department Heads (CIEADH).[6]

Comparison of Two Courses

The broad comparison of ergonomics classes at the authors' universities is shown in Table 2. There are many similarities and a few differences. Most of the differences are programmatic, rather than classroom specific.

Similarities: University A and University B are similar in that they both require a prerequisite course in basic Methods and Standards as well as a basic course in probability and statistics prior to taking Ergonomics. They both have an extensive lab component with written reports used for learning assessment and incorporate a student project. They both include physical and cognitive ergonomic concepts with a foundation in the PE Exam topics, and they both require student projects.

Differences: Term length for University A is sixteen weeks, while a University B term is just eleven weeks in length. The University B course requires a design project that is enabled by students' workplace scenarios, because their program requires that all students obtain cooperative employment. The University A course requires a team project where students write a paper and create a 5-minute YouTube video. Project topics are chosen by the students and can come from one of three categories: a contemporary ergonomic issue, an ergonomic analysis and redesign, or a case study of an historical system failure related to ergonomics. University B requires eight lab reports, while University A requires four lab reports, homework assignments and case study analyses. University A has a larger class enrollment.

Table 2. Comparison of ergonomics classes at two universities

	University A	**University B**
Pre-requisites	Methods and Standards Probability and Stats II	Work Design I: Methods and Standards Probability and Stats I
Length of term	16 weeks	11 weeks
Credit hours	3 credits	4 credits
Contact hours per week	2.5 hours of lecture 4-5 lab session per semester	3 hours of lecture 2 hours of lab
# of lab reports	4	8
Textbook	*Human Factors in Engineering and Design*, 7th Ed., Sanders and McCormick (1993)	*Niebel's Methods, Standards and Work Design, 13th Ed.*, Freivalds and Niebel (2013)

Table 3 shows that our two courses cover most of the topics contained in the FE Exam, Category 10. Some differences exist in the number of lecture hours devoted to these topics, but the coverage is surprisingly similar, given that the courses have different term lengths, one has more of an emphasis on lab experiments and the two courses use different textbooks.

Table 3. Comparison of Course Topics to FE Exam between Universities A and B FE Industrial Engineering Category 10: Human Factors, Ergonomics and Safety	University A Lecture Hrs	University B Lecture Hrs
A. Hazard identification and risk assessment	2	2
B. Environmental stress assessment (e.g., noise, vibrations, heat)	1*	5
C. Industrial hygiene	0	0
D. Design for usability (e.g., tasks, tools, displays, controls, user interfaces)	8	5
E. Anthropometry	5	5
F. Biomechanics	4	5
G. Cumulative trauma disorders (e.g., low back injuries, carpal tunnel syndrome)	4	5
H. Systems safety	1	1
I. Cognitive engineering (e.g., information processing, situation awareness, human error, mental models)	6	5
Other Topics	9	7

*An additional 8 hours is devoted to this topic in another required course (Methods and Standards)

Survey Results

An interesting survey recently conducted provides additional data to supplement the comparison of our two courses. In the summer of 2015, the Council of Industrial Engineering Academic Department Heads (CIEADH) and the NCEES PE and FE Exam Committees for Industrial Engineering sponsored a survey of ABET accredited Industrial Engineering programs to determine how their curricular content compared to the Industrial Engineering topics on the FE Exam.[6] Of the 23 Industrial Engineering programs responding to the survey, 13 answered the questions related to Category 10: Human Factors, Ergonomics and Safety. The survey asked the respondents to indicate the name of the course that primarily addressed the topics in each category; Table 4 contains this information.

Table 4. Course Names Indicated by 13 Survey Respondents[6]

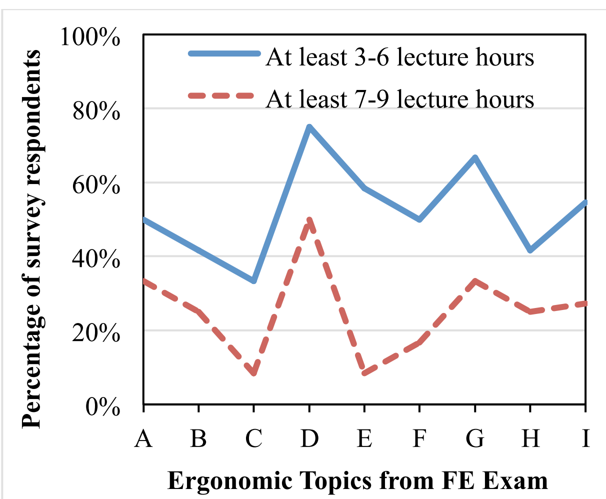
Category 10: Human Factors, Ergonomics and Safety	**Frequency**
Ergonomics	4
Human Factors	4
Methods Engineering	2
Safety Engineering	2
Cognitive Engineering	1

One interpretation from the response rate might be that only 13 of the 23 IE programs participating in the survey (56.5%) have a required class that teaches ergonomic topics. While this could be correct, we do not feel this is representative of the 94 programs reported on in Fraser, 2015.(ref) As stated earlier in this paper, Fraser concluded that 90% of ABET accredited

IE programs require “work methods, human factors, or ergonomics.” There were also 13 survey respondents that reported on courses that covered the topics in Category 11, Work Design, but the only course name that appears on both lists is “Methods Engineering” with a frequency of two for both categories. One possible explanation is that two programs reported on a single course that covers the topics in both Categories 10 and 11.

It should be noted that the survey appears to represent only 13 ergonomics courses. While a relatively small sample, the data are valuable because this survey is the only source that we have found that looks specifically at the topics covered in ergonomics courses taught by IE departments.

Figure 2 shows the percentage of programs that spend at least 3-6 hours (and at least 7-9 hours) of lecture devoted to topics A-I in Category 10. Of the nine topics (A-I), topic D, design for usability (e.g., tasks, tools, displays, controls, user interfaces) receives the most coverage, with 75% of the respondents spending at least 3-9 lecture hours on this topic and almost 50% of respondents spending at least 7-9 hours on design for usability. Topics that receive less lecture time than the others include topics C (Industrial hygiene) and E (Anthropometry). No statistical conclusions can be drawn from this data due to the relatively small sample size (13 respondents) and the variability in the courses. Two of the courses in question are entitled “Safety Engineering,” while one is entitled “Cognitive Engineering.” The survey design does not allow us to know if the schools with these specialized courses may also have a more general introductory course in Human Factors or Ergonomics that we are trying to characterize.



FE Exam Topics, Category 10
A. Hazard identification and risk assessment
B. Environmental stress assessment
C. Industrial hygiene
D. Design for usability
E. Anthropometry
F. Biomechanics
G. Cumulative trauma disorders
H. Systems safety
I. Cognitive engineering

Figure 2. CIEADH/NCEES Survey Data on Ergonomics Topics[6]

IV. Evolving Industry Needs

In order to determine the topics necessary to include in a course that is tied to the workplace, it is necessary to understand where people are working. According to the United Nations Industrial Development Organization[17] manufacturing remains a key driving force of the overall economic growth of developing and emerging industrial economies. However, the World Economic Forum predicts that robots will cause the net loss of 5.1 million jobs in their prediction of a fourth industrial revolution.[14] These robots will affect more than just manufacturing. In fact, the article states:

> *Developments in fields including robotics, big data, and artificial intelligence will change workplaces and the required different skills from workers in the years to come, according to "The Future of Jobs" report. Not everyone will be impacted equally, with the report concluding that the jobs most at risk are office and administrative roles. Other industries with negative job outlooks include manufacturing and production, the arts and entertainment, construction and extraction, and installation and maintenance. Overall, automation and robotics will cause 5.1 million job losses over the next five years, the researchers found.*

While manufacturing and office jobs may require fewer workers and different roles for the remaining workers, the medical field will likely continue to require the interaction of people to perform lifting tasks to transfer and care for patients. In fact, the aging population of Baby Boomers and increased life expectancy may have a significant impact on this portion of the workforce and the ergonomic issues involved.[10]

According to the Bureau of Labor Statistics,[3] Industrial engineers held about 241,100 jobs in 2014. The industries that employed the most industrial engineers were as follows:

- Computer and electronic product manufacturing 13%
- Machinery manufacturing 9
- Aerospace product and parts manufacturing 8
- Motor vehicle parts manufacturing 6
- Engineering services 5

This list suggests that a significant portion of the Industrial Engineering workforce is still engaged in the manufacturing sector. The healthcare and service sector are only recently realizing the value of Industrial Engineering skills.

Of the nearly 3.0 million nonfatal occupational injuries and illnesses in 2014, 2.8 million (95.1 percent) were injuries. Among injuries, nearly 2.1 million (75.0 percent) occurred in service-providing industries, which employed 82.4 percent of the private industry workforce. The remaining nearly 0.7 million injuries (25.0 percent) occurred in goods-producing industries, which accounted for 17.6 percent of private industry employment.[4]

The knowledge economy requires computers in most every job. By 2003, more than half of all workers in the United States used a computer[5] and the number of computers in use worldwide exceeded the 1 billion mark in 2008.[16] Thus, humans will necessarily be required to interact with computers and the idea of Human Computer Interaction (HCI) will be essential in the design of computer program development. In addition to Computer Scientists and Computer Engineering, the essential role that the IE plays in effective HCI should be included in the undergraduate ergonomics class. The Wall Street Journal stated that the humans who use computer systems are those system' critical weakness.[1]

V. What impact should these changes have on what we teach?

The ergonomics course naturally appeals to applications of industry scenarios and should always evolve with contemporary issues. While the program constraints might limit the ability of an instructor to dramatically change content in a packed course, topics can be changed with varying emphasis with very little cost or curriculum revision. There is clearly an opportunity for upper-class senior level electives to cover specific topics in more depth. However, it is always important to maintain a strong foundation of ergonomics concepts outside of the latest trends. Human beings will always be part of the workplace with varying types of working tasks on daily basis. Now, to answer the expanded question "What should be included in a required ergonomics course at the undergraduate level in order to prepare our IE graduates for a changing workplace?"

The FE Exam topics were shown to be in alignment with HFES Core Area 1 and provide foundational topics relevant to a required ergonomics course at the undergraduate level. University A and B ergonomics courses both offered roughly 80% of the total lecture hours to cover these standard topics leaving roughly 20% of lecture hours to be devoted to applying foundational topics to workplace needs.

Future work should include assessment of appropriate level of coverage based on website reviews of benchmark schools and industry consultation to enable a best practice syllabus to be developed for future offerings. The use of feedback and assessment metrics must be utilized as they relate to teaching ergonomics while evaluating the changing needs of industry

The authors intend to continue collaboration around building, improving and sustaining exceptional undergraduate ergonomics classrooms and labs to meet the needs of the changing workforce. Continuous improvement in the classroom necessitates alignment with professional organizations and industrial partners. Faculty collaboration and class comparison makes the process meaningful.

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