SAFETY AND ERGONOMICS TRAINING

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ABSTRACT

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This report summarizes the activities during the period of 07/01/11 through 06/30/16 for the Occupational Safety and Health (OSH) graduate training program in Industrial and Systems Engineering (ISE). Our aims were to provide a thorough education to trainees, to have them conduct high quality basic and applied research, and to provide service to the OSH profession, to industry, and to society. Our program emphasized three aspects of OSH at the MS and PhD levels: safety engineering, occupational ergonomics / biomechanics, and construction--sector OSH. Our program was characterized by a dual emphasis on breadth of trainee experience and the requirement for specialization, the latter emphasized by the need for a formal research project related to OSH. TPG funds helped us to maintain this emphasis, and to attract and retain top students. A broad yet cohesive group of faculty supported the program. Training was achieved through a combination of formal coursework, faculty advising, research, and more general exposure through seminars and interdisciplinary interactions. Candidates for our program were MS or PhD students accepted within the Human Factors Engineering and Ergonomics graduate concentration within the Industrial and Systems Engineering Department. Prospective trainees were also actively recruited through several means. TPG funding helps support our long-standing program, which provides the only comprehensive graduate-level training in OSH in the Commonwealth of Virginia. Our program overall was quite successful during the prior period, based on the number of graduates, the high proportion of graduates continuing in the OSH field, faculty and trainee scholarly output, awards, and the continuing high number of applications received. Program funds were used to support two trainees per year, with seven different students supported. Within the program as a whole, 23 trainees completed the program. Of these, the majority were subsequently employed in an OSH field or enrolled in an OSH academic program. Nearly half were women, and we have recently been successful in recruiting underrepresented minorities into the program. Many program graduates have leading administrative positions or academic appointments related to OSH. Program trainees published extensively on OSH topics in the reporting period. Several aspects of the program were modified or expanded, to enhance training opportunities and training experiences, including a new field-based OSH practicum.

HIGHLIGHTS / SIGNIFICANT RESULTS

Significant developments and accomplishments of the program during the reporting period are provided here in terms of trainees, administration, faculty participation, and facilities. Additional details are provided in the subsequent section. Virginia Tech has received funding from NIOSH training grants since 1992, and this funding has served a vital role in maintaining the program, which is the only one of its kind in the Commonwealth of Virginia. The TPG at Virginia Tech, housed in the Department of Industrial and Systems Engineering, emphasizes three aspects of occupational safety and health (OSH) at the MS (thesis) and PhD levels: safety engineering, occupational ergonomics, and construction OSH. The former two aspects have been a concentration of the program for several years, while the latter emphasis benefits from the collaboration between several academic and research units at Virginia Tech: Department of Industrial & Systems Engineering (ISE), the Myers-Lawson School of Construction, Department of Civil & Environmental Engineering, and the VT Occupational Safety and Health Research Center (OSHRC). Primary highlights of the program are: 1) the diversity of faculty expertise participating in student training; 2) the requirements for comprehensive and relevant coursework; 3) a required research experience related to occupational safety and health (OSH), and which contributes towards occupational hazard/risk recognition, avoidance, or control; and 4) professional development through participation in seminars, tours, and conferences.

During the project period, 23 trainees completed the training program (5 MS and 18 PhD). Seven trainees were supported using program funds, and five funded trainees completed the program (all PhD). A continued high proportion of trainees were at the doctoral level, largely as a result of: 1) changes in applicant demand; 2) continuation of MS students in the PhD program; and 3) an increased institutional emphasis on doctoral-level training across all fields. Scholarly outputs of trainees were substantial, with a number of publications generated in respected archival journals. A majority of trainees obtained employment with some aspects of occupational safety and/or health, including several who obtained tenure-track faculty positions. A recent survey indicated strong, positive support of experiences of recent graduates of the training program.

Several administrative and leadership changes occurred. Dr. Maury A. Nussbaum continued as PI/PD, Dr. Deborah Dickerson as co-director. Drs. Michael Agnew and Thurmon Lockhart left Virginia Tech during the reporting period. However, we also benefited from the additional of three new faculty members. Dr. Divya Srinivasan, and expert in occupational ergonomics and biomechanics, joined us in January, 2016 as a co-director. Drs. Joe Gabbard and Nathan Lau joined the faculty and training program as additional supporting faculty. Faculty participation was both high and diverse, covering a wide range of topics within safety engineering, human factors, and ergonomics.

OUTCOMES / RELEVANCE / IMPACT

Major outcomes of the program are related to the trainees, including their subsequent employment and scholarly output. During the project period, 23 graduate students completed the training program (5 MS and 18 PhD). Seven trainees were supported using program funds, five of whom completed their training. Of the program graduates, most (14/23) were subsequently employed in an OSH field or enrolled in an OSH academic program. Given the level of under-representation of women and minorities in the fields of OSH, we were successful in training such individuals in the reporting period. Specifically, a majority of funded trainees (4/7) were female, and nearly half of our 9/23 of all program trainees were women. Program trainees generated substantial scholarly output. TPG-supported trainees generated 21 publications (8 in conferences and 13 in archival journals) in the reporting period.

The major outcomes noted above are highly relevant in the context of occupational safety and health in general and in our training program specifically. First, work-related accidents, injuries, and illnesses continue at high levels across many sectors, and much of our training was focused on contributing to a better understanding of the causes and the development and evaluation of methods for alleviating these. Second, we continue to have substantial student interest in these sub-disciplines, not only from within the US, but from around the world. Third, we believe the breadth of experience we emphasized in our program is necessary to adequately prepare students in OSH areas, and to maximize the likelihood of their success after graduation. Fourth, the need for talented graduates in OSH continued, as indicated by the numerous requests from companies and consulting firms that we received for student applications. Fifth, we have graduated approximately 150 students from our program, and a majority of these former trainees are currently working in areas related to their training. Sixth, our program is the only one in the Commonwealth of Virginia that provides depth and breadth of training in these fields. We also served a regional need, in that we are not located within close proximity to any current ERCs (the nearest being UNC-Chapel Hill and Johns Hopkins). In addition, we are located in a rural area and provided expertise and potential employees that can serve in capacities beyond the specific OSH training they receive (e.g., most receive more general training in industrial and systems engineering).

Specific impacts of the program are more difficult to identify and/or quantify. Two items, however, are worth noting. First, as noted above, most of our former trainees (historically, and in the recent reporting period) continue to work in areas of OSH after graduation. Many of these former trainees have leadership positions in industry and several others are conducting OSH research and training in academic positions. Second, the scholarly output generated by our trainees is often cited by others, which indicates that their work is having an impact on others in the OSH field. In large part, the breadth of these impacts is related to our research diversity and our expansion of the program to included doctoral-level OSH training.

TECHNICAL REPORT

Overview

Building on the academic and research strengths at Virginia Tech, our training program emphasized three aspects of occupational safety and health (OSH): safety engineering, occupational ergonomics/biomechanics, and construction OSH. The first is a "core" discipline, the second a "related" discipline, and the third includes both core and related disciplines within the specific industrial sector of construction. The program itself is an academic "concentration" within the ISE graduate program. A safety engineering emphasis was implemented nearly 35 years ago, and training support as a NIOSH TPG began in 1992. In 2002, the program was expanded to include MS students with training interests in occupational ergonomics and biomechanics. This expansion was done to reflect several changes that had occurred in program faculty, student interests, contemporary needs in research and industry, and ongoing research projects.

Expanding the training program scope to include a focus on construction OSH is another recent development, but a natural outcome of recent research efforts. In the past decade, Virginia Tech has emerged as a leader in the field of construction engineering and management in general, and construction safety and health in particular. With its Vecellio Construction Engineering and Management Program, Department of Building Construction, Myers Lawson School of Construction, and the NIOSH-sponsored Center for Innovation in Construction Safety and Health, Virginia Tech offered significant training opportunities to graduate students interested in occupational safety and health within this important economic sector.

The core rationale for our proposed training project can best be summarized by our department's (Industrial and Systems Engineering–ISE) mission statement, copied below.

1) Provide a high quality education that will prepare our undergraduate and graduate students for a life-long learning experience in this rapidly changing field, and to prepare these students to be future leaders in the industrial engineering profession, in business, in industry, and in academia.
2) Conduct high quality basic and applied research to advance the frontiers of engineering and to support the industrial and economic growth of the Commonwealth of Virginia and the nation as a whole.
3) Provide service to the profession, industry, and society to contribute to the advancement of civilization and the betterment of all.

Several points emphasize and justify the need for training in our program's areas of focus. First, work-related accidents, injuries, and illnesses continue at high levels across many sectors, and much of our training is focused on contributing to a better understanding of the causes and the development and evaluation of methods for alleviating these. Second, we continued to have substantial student interest in these sub-disciplines, not only from within the US, but from around the world. Third, we believe the breadth of experience we emphasized in our program was necessary to adequately prepare students in OSH areas, and to maximize the likelihood of their success after graduation. Fourth, the need for talented graduates in OSH continued, as indicated by the numerous requests from companies and consulting firms that we receive for student applications. Fifth, we have graduated nearly 150 students from our program, and a majority of these former trainees are currently working in areas related to their training. Sixth, our program is the only one in the Commonwealth of Virginia that provides depth and breadth of

training in these fields. We also serve a regional need, in that we are not located within close proximity to any current ERCs (the nearest being UNC-Chapel Hill and Johns Hopkins). In addition, we are located in a rural area and provided expertise and potential employees that can serve in capacities beyond the specific OSH training they receive (e.g., most receive more general training in industrial and systems engineering).

Our program interfaced closely with several other current training activities at Virginia Tech. These are primarily through overlapping participation in several centers, including the Occupational Safety and Health Research Center (led by Nussbaum), the Center for Gerontology, and with the School of Biomedical Engineering and Sciences (Nussbaum is a core member). Nearly all of our trainees were also involved with our student chapter of the Human Factors and Ergonomics Society. Membership of students in the American Society of Safety Engineers student chapter continued to grow, and also included students in Civil and Environmental Engineering and Psychology. As a formal relationship, and as noted above, students in the program were part of the HFEE graduate concentration area within ISE, specifically MS (thesis) and PhD students.

Primary purposes and objectives of our TPG were in parallel to those given above as the rationale: to provide a high quality education (at the MS and PhD levels), to conduct high quality research, and to provide service. With respect to TPG funding, this was (and is) used primarily to attract and maintain top students, maintain a critical mass of students, support our curriculum, and facilitate meaningful research that is not otherwise funded. Program funds also allowed us to maintain our program breadth, which in turn also helped attract and support students.

Our training activities occurred in three areas. The first was traditional didactic presentation of instructional material (lecture). Specific curricula requirements were developed to ensure both breadth and depth of exposure, and are described in the Program Plan. The second was a formal research experience (coaching). All program participants were required to generate either a thesis or dissertation, and most of these led to publications either at a conference or in an archival journal. The third was professional development (seminar/discovery learning), which is described below and was intended to “round out” the trainees’ educational experiences. In addition, more hands-on experience (coaching) is achieved through an OSH Practicum, which was started during the reporting period.

Program Leadership and Faculty

Dr. Maury A. Nussbaum, Professor in ISE, was PI and directed the grant and Training Program, served as the NIOSH liaison, and managed budgetary issues. Dr. Nussbaum assumed the director’s role in 1999. Dr. Dickerson continued as TPG co-Director, and Dr. Srinivasan joined as a second co-Director upon joining the faculty in January, 2016. Earlier, Drs. Agnew and Lockhart left Virginia Tech, and Drs. Gabbard and Lau joined the faculty and were added as supporting faculty to the TPG. As a group, Drs. Nussbaum, Dickerson, and Srinivasan provided relevant expertise in the primary training areas (safety engineering, occupational ergonomics, and construction OSH).

This core administration also received input from two sources (internal and external advisory committees and feedback from past trainees). An *Internal Advisory Committee*, consisting of all TPG faculty. The Internal Advisory Committee discussed the status of the program on a regular basis, to review the program performance and address any substantial operational issues.

Smaller-scale issues were discussed by email, moderated by the program director. Continuing feedback regarding the program operations and opportunities for improvement was obtained early in the reporting period from an *External Advisory Committee*, but this is being reorganized to enhance interdisciplinary strengths. Trainees completing the program, as well as prior trainees, provided informal feedback to the core administration.

The individuals listed below each contributed to the training program during the prior reporting period. All were full-time, on-campus faculty. Except for Dr. Young-Corbett, who is in the School of Construction (tenure department = Civil & Environmental Engineering), each was a full-time, on-campus faculty member in the HFEE concentration area within ISE. This faculty represented a diverse combination of expertise in the areas of safety engineering, occupational ergonomics, occupational biomechanics, and industrial hygiene.

Core Faculty	**Areas of Primary Expertise Relevant to the Program**
Dr. Maury A. Nussbaum	Occupational Biomechanics; Physical Ergonomics; Fall Prevention
Dr. Deborah Dickerson	Construction Hazard Control; Industrial Hygiene; Construction OSH; Indoor Environmental Quality; Prevention through Design
Dr. Divya Srinivasan	Occupational Ergonomics & Human Performance; Workstation Design; WMSDs

Supporting Faculty	**Areas of Expertise**
Dr. Joseph Gabbard	Augmented & Virtual Reality; Perception & Cognition; Interface Design; Usability Engineering
Dr. Nathan Lau	Cognitive Engineering; Interface Design; Human Performance Assessment; Situation Awareness

Mentoring of trainees occurred through both formal and informal mechanisms. Formal mentoring occurred primarily through advising of student research at both the MS and PhD levels. A research project was required at both levels, and program faculty served as major advisors and committee members for trainees. Informal mentoring occurred through several mechanisms. Organized by our student HFES chapter, there were several “brown bag” seminars led by faculty and students each semester. In addition, the core program faculty provided mentoring as needed, pro-actively based on our tracking of student progress, and at a trainee’s request.

Collaboration among our faculty and among trainees was extensive. Faculty also served mutually as members of trainee MS and PhD committees. Program faculty were active in a diverse set of research areas and funded projects. This research support, in turn, provided increased exposure to trainees on a variety of contemporary topics, and much of this funding allowed for student support in addition to that provided by the TPG.

Program Description

Our program was designed to provide training in three aspects of OSH: safety engineering, occupational ergonomics, and construction OSH. Here, occupational ergonomics includes WMSD prevention, occupational biomechanics, and work physiology. Training was offered at both the MS (thesis) and PhD levels. Trainees in the program formed a subset of ISE graduate

students, within the Human Factors Engineering and Ergonomics (HFEE) graduate concentration. This was done using separate curricular requirements ("tracks") within the department. We used TPG funds to support (typically) two full-time students per semester. The program as a whole, however, had annual enrollments of ~10 MS (many non-thesis) and ~10 PhD students.

Separate coursework and training requirements existed for MS and PhD students, which were implemented and administered as "tracks" as indicated earlier. Note that the ISE graduate program as a whole is organized into several tracks (or concentrations), including general IE, human factors & ergonomics, manufacturing systems, operations research, and management systems. During the reporting period, the PhD curriculum requirements were updated in the form of a specialized Occupational Ergonomics and Safety "Concentration". While graduate students can obtain a non-thesis MS degree, only thesis students were considered part of the training program. Trainees typically completed their training in ~2-2.5 years for the MS and 4-5 years for the PhD. Many MS students required the second summer or a fifth semester to complete the program. Most PhD students were able to complete their training in three years, post MS (increasing numbers of PhD students, though, were directly admitted post-BS to be competitive with other programs). During their training period, student progress was monitored and evaluated primarily by the advisor and the trainee's committee. In addition, the program director (Nussbaum) communicated at least once per semester with each trainee, and the ISE department completed a formal review process for each trainee at the end of each academic year.

MS Training

MS trainees completed a formal research project (thesis option) and 31 credit hours beyond the baccalaureate. Of these, at least 25 credit hours (eight courses) were formal coursework. All program MS trainees completed a set of four "core" courses and a required ISE department seminar (0 credit hours). These core courses provided a fundamental exposure to major aspects of human factors / ergonomics and experimental design / statistics, as well as more detailed exposure to human mental and physical abilities and limitations. MS trainees also completed a minimum of four elective courses. Sets of "pre-approved" electives were provided, though trainees could deviate (with advisor and committee approval) from these as warranted by their current and future interests as well as to accommodate new or irregular course offerings. Our intent with these electives was to build expertise (on top of the foundational coursework), and to allow students the flexibility to develop specialization within a sub-discipline.

PhD Training

PhD trainees had the same "core" coursework requirements as for MS trainees. In addition, each needed to broaden their expertise in experimental design and statistics, by completing additional coursework on these topics (e.g., multivariate, non-parametrics). They also completed a set of elective courses. Pre-approved electives are identified. An individualized, hands-on approach was taken with each trainee in terms of selecting coursework, led by the advisor and committee and with support of the TPG director. Overall, the intent was to ensure adequate breadth in OSH through coursework while also supporting the development of specific expertise in the trainee's research domain(s).

Common Requirements for MS and PhD Training

Beyond the didactic course requirements indicated above, both MS and PhD trainees had several requirements set by the ISE department. Each had to complete a plan of study (within their first year of graduate school), in which the set of courses intended to meet the

requirements was listed, and which was approved by the student's advisor, committee, and ISE graduate program director. Both advisors and committee members were selected by the student, with input as needed from any program member. A formal research proposal was required, with a written version distributed to the student's committee followed by a formal oral presentation (proposal defense). For trainees in our program, the research had to be focused on OSH or have clear OSH relevance. Upon committee approval of the proposal, students commenced their research, with a department-required progress meeting occurring at least once before the final defense. The research was presented in written form (thesis/dissertation) to the committee, again followed by an oral presentation (final defense). All students were required to show evidence of prior or intended publication of their research at the final defense. In addition to these requirements, PhD students took a preliminary exam prior to generating their research proposal. This is a two-week written exam, with questions submitted by the advising committee, followed by a two-hour oral exam. Consistent with graduate school requirements, all trainees had to maintain a GPA ≥ 3.0 (B); if this was not achieved, trainees were placed on academic probation and had one semester to reach compliance. No trainees dropped or were removed from the program.

Trainee Research and Interdisciplinary Experiences

All MS and PhD trainees within the program participated directly with research activities. In large part this was related to the formal research requirements, but such participation was almost always broader for several reasons. First, students became members of laboratories directed by their advisors, and hence were exposed to other work being undertaken there. Second, defenses are typically open, providing exposure to work throughout the HFEE area. Third, students often volunteered to either serve as experimental participants or to assist with data collection. Specific student research projects were chosen at the discretion of the student and their advisor. These were typically either new topics developed by the student, or extensions of existing work being done by the faculty advisor. Each student was expected to make a new intellectual contribution (e.g., simply performing work that had been proposed by a faculty advisor in detail would not be considered acceptable).

Students were also expected to broaden their educational experience by attending seminars within and outside the university, department, and disciplinary are. As noted above, there were several offered by faculty and students within HFEE. In addition, our student HFES chapter was quite active, and hosted 2-3 speakers on basic and applied topics each semester. We have not formally enforced any requirements to attend seminars, as we have found that students attend these voluntarily (many are standing room only). Most of our students attended the annual HFES conference, either supported by their advisors or using travel supplements provided by our TPG, the university, or the student HFES chapter.

Our program sought to ensure that graduates were equipped to recognize, evaluate, and control occupational hazards. They received special knowledge in diverse areas, such as: system safety analysis, industrial fire control, ergonomics, toxicology, acoustics and hearing protection, industrial hygiene, injury epidemiology, accident analysis, occupational biomechanics, low-back disorders and WMSDs more generally, radiation protection, machine guarding, electrical hazards, experimental design, and statistical analysis. It is this combination and breadth of interdisciplinary material that we believe keeps our program in demand. The combined program faculty are unusual in ergonomics and human factors programs because of the breadth and interdisciplinary backgrounds they bring.

Our program also fostered interdisciplinary interactions. We cooperated in particular with Civil Engineering, Engineering Science and Mechanics, The School of Construction, The School of

Biomedical Engineering and Sciences, Computer Science, Statistics, and Psychology. This cooperation took place through exchange of students, encouraging students to take classes in other areas, cross-discipline research, and committee work. Dr. Nussbaum has affiliated status with Mechanical Engineering and Biomedical Engineering, as well as the Center for Gerontology. Dr. Dickerson has appointments in Civil and Environmental Engineering, the School of Construction, Building Construction, and Industrial and Systems Engineering. Her laboratory is also fully equipped for industrial hygiene sampling and analysis of particulate and chemical air contaminants.

Virginia Tech has very active student chapters of the American Society of Safety Engineers (ASSE) and Human Factors and Ergonomics Society (HFES). The HFES chapter is one of the largest in the nation (and consistently receives "Gold Level" recognition). These chapters regularly conducted site visits to local industries and engineering laboratories, and hosted formal seminars and "brown-bag" lunches by safety researchers and professionals. These interdisciplinary exchanges occurred on a continuing basis and were a vital part of both faculty and student experience.

Students in the core and allied programs frequently interacted through the mechanisms described above (meetings, gatherings, etc.) and through coursework. While students in the program took elective courses specific to their interests, there was overlap among students in these, and along with the core course requirements the curriculum ensured that all program trainees interacted with each other and with students in other disciplines. Interaction among trainees was further facilitated through performance of project requirements associated with classes. In these cases, projects were often student selected and usually student groups were selected to combine student expertise across multiple areas.

Instruction in the Responsible Conduct of Research

Formal instruction on scientific integrity and ethical principles has been part of our graduate training for several years, and continued throughout the reporting period. Ethical principles guiding the use of human subjects in research were discussed in three courses offered in the program: ISE 5615 Human Factors Research Design, ISE 5674 Systems Safety, and ISE 5694 MacroErgonomics. In ISE 5615 and 5674 there are units wherein the information was presented in lecture format complemented by handouts and source identification for additional information. Topical content areas covered included conflict of interest (5615, 5674, 5694), data management and sharing (5615), human subject use (5615, 5674, 5694), relationship between the institution and graduate students (5694), and professionalism and ethics in human factors and ergonomics intervention (5694). ISE 4644 (Occupational Safety and Hazard Control Course) also addressed scientific integrity, research and professional ethics, and ethical practices in general by covering the fundamental canons of industrial engineering and professional ethics requirements for Industrial Engineers. Research ethics was also extensively covered in a new elective course (ISE 6624) on "Proposing IE Research". This course is offered every other year (by Nussbaum), and was taken by many program doctoral trainees. Finally, all funded trainees were required to complete formal training on research ethics and conflicts of interest.

All trainees performed research using human subjects (or data obtained from human subjects). As such, they were required (by the VT IRB) to complete an on-line web-based training module and successfully pass the module, or complete alternative comparable training (e.g., from the NIH website). Documentation of such training was required before an IRB application is approved.

Training Candidates

Trainees in our program were candidates for the Master of Science and Doctor of Philosophy within the Human Factors Engineering and Ergonomics (HFEE) concentration area in the Department of Industrial and Systems Engineering. Trainees all held baccalaureate degrees in engineering, science, or cognate area from an accredited college or university. They were admitted competitively based on grade point average, letters of recommendation, personal statements, work experience, and standardized test scores. Admissions were handled centrally in the Department, though primarily based on individual faculty input. Admission standards were consistent with graduate school minimal requirements or recommendations: GPA (3.0), TOEFL (80 iBT) or IELTS (6.5), GRE (146V, 141 Q, and 3.0A).

Once accepted, there was an open competition between the students for NIOSH training grants. Awardees were selected each year based on current GPA, program experience, and their stated goals for their participation in the program. Students who were in their second year in the program and were ready to conduct a research project were given priority, as were trainees funded previously and who had made good progress through their program. Funding was limited to those who meet citizenship requirements. Students who did not receive TPG funding usually received other support from the Department in the form of Graduate Research Assistantships, Graduate Teaching Assistantships, and Graduate Fellowships.

Prospective trainees were also actively recruited through our web page, from program brochure mailings, and from active participation of both faculty and students in conferences. We drew students from around the US, and with major sources of international applicants from China, Korea, and India. Approximately 30-50 applications were received each year for the entire program (HFEE area within ISE). Of these, roughly 50-60% were accepted and ~10-15 enrolled each. Of the HFEE students who matriculated, roughly half pursued research is some aspect of OSH. Over the last several years, we have had 3-5 candidates per year for our two NIOSH traineeships.

Consistent with earlier college and departmental changes in focus, specifically increasing their emphasis on doctoral-level training, we had more applications and more enrolled students at this level in our program. We continue to try to address this issue, and plan to continue our recruiting efforts on MS trainees. Our program continued to contribute to the role of TPGs in ensuring “an adequate supply of qualified professional occupational safety and health practitioners and researchers.” While year-to-year we had a changing balance between practitioner- and researcher-focused trainees, our overall goal in recruiting and training were to achieve both products to the extent possible. We will continue to work with the Multicultural Academic Opportunities Program and the Office of Diversity and Inclusion to enhance diversity of under-represented minorities and women in the program.

Training Facilities and Resources

Our training facilities included a number of laboratories that were used on a regular basis for OSH-relevant research and instruction:

- Cognitive Engineering for Novel Technologies (COGENT)
- Occupational Ergonomics and Biomechanics (OEB) Laboratory
- Locomotion Research Laboratory (LRL)

- Safety Engineering Laboratory (SEL)
- Virginia Cognitive Systems Engineering Laboratory (VCSEL)
- Occupational and Construction Hazard Reduction Engineering (OCHRE) Laboratory

Other facilities included those normally found at a major University and include dedicated, multimedia classroom space, computer laboratories, and faculty and student office space. Additional research support was provided by the Industrial and Systems Engineering Department in the form of office space for all graduate students (each office containing a networked computer with software), supplemental funds for subject fees and travel, and a fully equipped machine and electronics shop with four full-time staff members.

Program Outcomes and Accomplishments

The Virginia Tech TPG was a component of the graduate program in the Department of Industrial and Systems Engineering (ISE). During the reporting period, the program consisted of MS (thesis) students with specific concentrations (Safety Engineering, Physical Ergonomics, and Occupational Biomechanics) and PhD students conducting research in occupational safety and health. Our program was very active over the past project period. This activity included several sponsored projects, numerous research publications, and awards to the faculty and trainees. The program also generated several program graduates (see below), who have been productive in research and gone on to careers in occupational safety and health.

Our program has been quite successful at recruiting and retaining students overall, and especially in enhancing program diversity. With respect to recruiting, we had applications from around the country and the world, from individuals with diverse backgrounds (engineering, psychology, math, physical therapy, etc.). In the prior reporting period, no trainees left the program, and the vast majority completed the program in a reasonable time period (i.e., 2.5 years for the MS and 4-5 years for the PhD); any exceptions to these have mainly been students who worked full or part time during their training. Roughly half of our prior and current trainees are females, and a substantial number are from minority and/or underrepresented groups.

We supported seven different trainees during the reporting period using TPG funds, all PhD students. Of these, five completed their PhD training. In total, there were 23 students who completed training, 5 MS and 18 PhD. There was a continued increasing proportion of trainees at the doctoral level, largely as a result of: 1) changes in applicant demand; 2) continuation of MS students in the PhD program; and 3) an increased institutional emphasis on doctoral-level training across all fields.

Of all program graduates, the majority (14/23) had subsequent employment in an OSH field or in an OSH academic program. Of note, eight PhD trainees obtained (and continue in) academic positions in which a main focus is OSH teaching and/or research. Others are currently in leading research, administrative, or applied/consulting positions.

Given the level of under-representation of women in the fields of OSH, we believe we were successful in training such individuals in the reporting period. Specifically, a majority (4/7) of our funded trainees were women, and almost half of the total trainees in the program (9/23). None were underrepresented minorities in the reporting period. However, we continue our recruitment efforts, and recently enrolled an African-American females and a woman whose ancestry is part Native American.

Diverse research products were generated by the program in the reporting period. Trainees supported by the program generated 13 and 8 papers in journals and at conferences, respectively. For the program as a whole, there were several dozen additional scholarly contributions.

In October, 2015 we developed and distributed an evaluation survey for use as a summative assessment of the program during the prior funding period. This anonymous survey was submitted to all (*n* = 21) program graduates during the funding period up to that time, and an additional 3 PhD trainees who had graduated in the prior 1.5 years. The response rate was 91.7% (22/24). Questions and responses are summarized below.

Responses to several statements were provided on the following Likert scale alternatives: 1 = Strongly Disagree (SD); 2 = Disagree (D); 3 = Neutral (N); 4 = Agree (A); 5 = Strongly Agree (SA).

Statement	SD	D	N	A	SA	N/A	Mean
1. My current career involves safety engineering, ergonomics, or construction safety work	1	3	3	5	10		3.91
2. My graduate studies at Virginia Tech prepared me for my current career	1	0	1	10	10		4.27
3. My graduate studies at Virginia Tech allowed me to gain experience in conducting formal research	0	0	0	4	18		4.82
4. My graduate studies at Virginia Tech enhanced my understanding of the major problems, theories, technologies, and tools in the fields of safety engineering, ergonomics, and/or construction safety	0	0	1	8	13		4.55
5. The Virginia Tech program prepared me for professional ergonomics practice	1	0	2	11	7	1	4.10
6. The Virginia Tech program prepared me for professional safety engineering practice	0	0	2	6	3	11	4.09
7. The Virginia Tech program enhanced my appreciation of lifelong learning	0	0	1	5	16		4.68

In addition, the following categories were indicated as best describing current employment:

- Academic (*n* = 6; 27.3%)
- Government Agency (*n* = 2; 9.1%)
- Consulting (*n* = 3; 13.6%)
- Healthcare (*n* = 2; 9.1%)
- Manufacturing (*n* = 3; 13.6%)
- Other (*n* = 6; 27.3%)

Finally, open-ended questions asked about the “most positive aspects” of their graduate studies and “suggestions for improvements”. Among the most frequent positive aspects noted were the

faculty, facilities, available projects, diversity of topical coverage, and mix of theoretical and applied knowledge. The most frequent suggestion noted was closer cooperation/relationships with companies and field experiences (note, most responders graduated prior to our implementation of the required SOH practicum). Also indicated was a desire for more of an international focus and more emphasis on and experience with design. Our program leadership is working to try to address these latter aspects.

Conclusions

Our program occupied a niche that is somewhat unique, given both the program breadth and depth. Diverse outputs and accomplishments were achieved, in terms of program graduates and research products. It was oriented strongly towards engineering aspects of OSH, while also being influenced by its place within the larger ergonomics and human factors engineering graduate concentration. Trainees were exposed to a wide variety of health and safety issues, including such topics as system safety, industrial hygiene, traditional physical ergonomics, engineering design, and human factors research methods.

The program was successful in terms of graduating a consistent number of well-qualified trainees, who generated substantial research products (e.g., journal and conference papers) and who have gone on to future careers emphasizing occupational safety and health. As was described above, however, the effects of TPG funds went well beyond the direct influence on student tuitions and stipends. The award was a key aspect in the maintenance and continual improvement of the training curriculum, and facilitated numerous other activities both intra- and extra-curricular.

The program has undergone some revisions during the prior project period. Among these, the major ones have been changes in leadership and faculty involvement, an increasing focus on doctoral-level training, and an expansion of the program to emphasis OSH in construction. A continual evolution will likely occur, as we strive to both improve and grow the program in the future.

PUBLICATIONS RESULTING FROM TRAINEES

The list immediately below contains publications that were generated by trainees supported by the training grant, and which represent work completed during their training period. Supported trainees are underlined. In addition to these, other trainees generated numerous journal papers (published or in-press) and conference presentations on topics related to occupational safety and health in the reporting period.

Journal Articles:

1. Mehta RK, Horton LM, Agnew MJ, Nussbaum MA: [2011] Ergonomic evaluation of hospital bed design features during patient handling tasks. International Journal of Industrial Ergonomics 41: 647-652.
2. Horton LM, Nussbaum MA, Agnew MJ: [2012] Effects of rotation frequency and task order on localized muscle fatigue and performance during repetitive static shoulder exertions. Ergonomics 55: 1205-1217.
3. Cavuoto LA, Nussbaum MA: [2013] Obesity-related differences in muscular capacity during sustained isometric exertions. Applied Ergonomics 44: 254-260.
4. Cavuoto LA, Nussbaum MA: [2013] Differences in functional performance of the shoulder musculature with obesity and aging. International Journal of Industrial Ergonomics 43: 393-399.
5. Horton LM, Nussbaum MA, Agnew MJ: [2013] Effects of rotation frequency and starting task on localized muscle fatigue and performance during simulated assembly work. IIE Transactions on Occupational Ergonomics and Human Factors 1: 176-189.
6. Cavuoto LA, Nussbaum MA: [2014] The influences of obesity and age on functional performance during intermittent upper extremity tasks. Journal of Occupational and Environmental Hygiene 11: 583-590.
7. Cavuoto LA, Nussbaum MA: [2014] Influences of obesity on job demands and worker capacity. Current Obesity Reports 3: 341-347.
8. Mi N, Cavuoto L, Benson K, Smith-Jackson T, Nussbaum MA: [2014] A heuristic checklist for an accessible smartphone interface design. Universal Access in the Information Society 13: 351-365.
9. Christian M, Nussbaum MA: [2015] An exploratory study of the effects of occupational exposure to physical demands on biomarkers of cartilage and muscle damage. Journal of Occupational and Environmental Hygiene 12: 138-144.
10. Christian M, Nussbaum MA: [2015] Responsiveness of selected biomarkers of tissue damage to external load and frequency during repetitive lumbar flexion/extension. International Journal of Industrial Ergonomics 48: 1-9.
11. Horton LM, Nussbaum MA, Agnew MJ: [2015] Rotation during lifting tasks: effects of rotation frequency and task order on localized muscle fatigue and performance. Journal of Occupational and Environmental Hygiene 12: 95-106.
12. Cullen RH, Agnew MH: [2016] Comparing different measures of overall workload in a multimodal postural/auditory dual-task environment. IIE Transactions on Occupational Ergonomics and Human Factors 4:115-127.

13. Gausepohl KA, Winchester WW, Smith-Jackson TL, Kleiner BM, Arthur JD: [2016] A conceptual model for the role of storytelling in design: leveraging narrate inquiry in user-centered design (UCD). Health and Technology 6: 125-136.

Proceedings:

1. Gausepohl K, Winchester W, Arthur JD, Smith-Jackson T, Kleiner B: [2012] Context matters: Design guidance for maximizing success of storytelling sessions during a user-centered design task. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Boston, MA, 767-771, October 22-26.
2. Cavuoto LA, Nussbaum MA (2012) Occupational issues related to worker obesity. Applied Ergonomics Conference. Nashville, TN. March 26-29. Abstract only.
3. Cavuoto LA, Nussbaum MA (2012) Effects of obesity on muscular capacity during sustained isometric exertions. Presented at the Industrial & Systems Engineering Research Conference (ISERC). Orlando, FL. May 19-23. Abstract only.
4. Christian M, Nussbaum MA (2013) Biomarkers as a potential tool for assessing work-related musculoskeletal disorder risk. Proceedings of the XXVth Annual Occupational Ergonomics and Safety Conference, Atlanta, GA. June 6-7. pp. 44-49.
5. Cavuoto L, Nussbaum MA (2013) Influence of obesity and age on upper extremity functional performance. Presented at the Industrial and Systems Engineering Research Conference (ISERC). San Juan, Puerto Rico. May 18-22. Abstract only.
6. Goldberg A, Young-Corbett D: [2014] Decision making in commercial construction. Human Factors in Organizational Design and Management XI: Nordic Ergonomics Society Annual Conference 46. Copenhagen, Denmark. August 17-20.
7. Goldberg A, Young-Corbett D: [2014] Adoption Readiness of Prevention through Design (PtD) Controls in Concrete, Masonry, and Asphalt Roofing. Construction Research Congress. Georgia Institute of Technology, Atlanta, GA; May 19-21.
8. Christian M, Nussbaum MA (2015) Biomarker responses to static axial trunk loading and unloading. Proceedings of the 4th Annual World Conference of the Society for Industrial and Systems Engineering, Ft. Lauderdale, FL. October 19-21, pp. 38-43.

Ph.D. Dissertations:

1. Horton L: [2012] The effects of job rotation parameters on localized muscle fatigue and performance: an investigation of rotation frequency and task order, Ph.D. Dissertation, Virginia Tech.
2. Gausepohl K: [2012] The Storytelling + Design Framework: Design Guidance for the Concept Phase of Medical Device Design, Ph.D. Dissertation, Virginia Tech.
3. Cavuoto L: [2012] Evaluating obesity-related differences in upper extremity and trunk muscular capacity, Ph.D. Dissertation, Virginia Tech.
4. Christian M: [2014] Biomarkers of physiological damage and their potential for work-related musculoskeletal disorder risk assessment, Ph.D. Dissertation, Virginia Tech.
5. Cullen R: [2014] Multimodal Multitasking: The Combined Effects of Postural and Cognitive Demands on Overall Workload, Ph.D. Dissertation, Virginia Tech.

M.S. Theses:

n/a

The following lists additional Dissertations and Theses generated by trainees who graduated in the reporting period

Ph.D. Dissertations:

1. Mehta, RK: [2011] Interactive Effects of Physical and Mental Workload: A Study of Muscle Function, Capacity, and Exertion Type, Ph.D. Dissertation, Virginia Tech.
2. Jongprathisporn M: [2011] The Age-Related Effects of Visual Input on Multi-Sensory Weighting Process During Locomotion and Unexpected Slip Perturbations, Ph.D. Dissertation, Virginia Tech
3. Clasing J: [2012] Title Restricted, Ph.D. Dissertation, Virginia Tech
4. Kim S: [2012] Development and Evaluation of Methods to Assess Physical Exposures in the Workplace using Wearable Technologies, Ph.D. Dissertation, Virginia Tech
5. Lee JY: [2012] Quantifying the effects of experience on motor behaviors during simulated occupational tasks, Ph.D. Dissertation, Virginia Tech
6. Jia B: [2013] Influence of Prolonged Sitting and Psychosocial Stress on Lumbar Spine Kinematics, Kinetics, Discomfort, and Muscle Fatigue, Ph.D. Dissertation, Virginia Tech
7. Toosizadeh N: [2013] In vivo measuring and modeling off viscoelastic behaviors of the trunk in response to flexion exposures, Ph.D. Dissertation, Virginia Tech
8. Zhang H: [2013] Developing and Evaluating New Methods for Assessing Postural Control and Dynamics, Ph.D. Dissertation, Virginia Tech
9. Muslim K: [2013] Posterior Load Carriage: Ergonomic Assessment and Intervention Efficacy, Ph.D. Dissertation, Virginia Tech
10. Zhang X: [2013] Fall Risk Assessment By Measuring Determinants Of Gait, Ph.D. Dissertation, Virginia Tech
11. Zhang J: [2014] Support Vector Machines (SVMs) Based Framework for Classification of Fallers and Non-fallers, Ph.D. Dissertation, Virginia Tech
12. Rashedi E: [2015] Localized muscle fatigue: theoretical and practical aspects in occupational environments, Ph.D. Dissertation, Virginia Tech
13. Wu X: [2015] Toward understanding factors affecting falls among individuals who are obese, Ph.D. Dissertation, Virginia Tech

M.S. Theses:

1. Mistry, A: [2011] Effects of Yoga on Low Back Stability, Strength and Endurance, M.S. Thesis, Virginia Tech.
2. Dorbala, V: [2012] Quantification of Cumulative Load on the Knee using a Vibration Emission Method, M.S. Thesis, Virginia Tech.
3. Toole, L: [2012] Crash Risk and Mobile Device Use Based on Fatigue and Drowsiness Factors in Truck Drivers, M.S. Thesis, Virginia Tech.
4. Angles, J: [2013] Usability of Fall Arrest Harnesses, M.S. Thesis, Virginia Tech.
5. Treff, M: [2014] An Investigation of Musculoskeletal Imbalances in the Thoracic and Cervical Regions, with Respect to an Improved Diagnostic Approach for Upper Crossed Syndrome, M.S. Thesis, Virginia Tech.