AC 2008-1091: ASSESSING STUDENTS' LEARNING OUTCOMES DURING SUMMER UNDERGRADUATE RESEARCH EXPERIENCES

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Assessing Students' Learning Outcomes during Summer Undergraduate Research Experiences

Abstract

Highly promoted and funded by NSF and other agencies, undergraduate research experiences have many benefits to students and also present a great opportunity for them to learn globally competitive skills. Having recruited 22 NSF REU sites nationwide to participate in this study, we present findings of students' (Pre-survey N=235 and Post-survey N=275) self-assessments of their learning outcomes using a validated survey instrument, National Engineering Students' Learning Outcomes Survey (NESLOS), which was derived from ABET criteria. Key findings of what students learned and valued, insight into how the undergraduate research experience can be improved, and student career path goals are presented. These findings can aid program directors, coordinators, and undergraduate research faculty advisors to improve their program and assessment efforts.

Introduction

Global competitiveness, outsourcing, and increased production of overseas engineers are issues that are becoming increasingly relevant in undergraduate engineering education and have prompted a number of calls to protect U.S. global competitiveness. All these reports have challenged engineering institutions to produce graduates with professional as well as technical skills by outlining the desired attributes for graduating engineers.

Undergraduate research experiences, which are highly promoted and supported by NSF and other agencies, present a great opportunity for our students to learn these essential globally competitive skills. Some of the benefits of undergraduate research are: (a) applying skills and knowledge learned in the classroom, (b) working with state-of-the-art processes, equipment, and tools, (c) gaining critical thinking skills, (d) gaining self-confidence, and (e) promoting advanced degrees and clarifying career goals. In spite of such widespread support and belief in the value of undergraduate research to improve education, the bodies-of-knowledge and learning outcomes comprising of the countless ways in which students benefit and learn from being involved in research projects have been insufficient and understudied. Most of the existing literature reveal the predominance of program descriptions and evaluation efforts, rather than studies grounded on research. Moreover, most of these studies on undergraduate research have focused on the sciences, whereas undergraduate research experiences in engineering are limited.

One of the most prominent studies on undergraduate research has been the work of Elaine Seymour and her research group [1-2]. Their five-year study on undergraduate research in STEM disciplines focused on four liberal arts colleges with a long history of undergraduate research programs. The work presented a comparative analysis of faculty and administrator interviews (N=80) with student interviews (N=76) and provides findings of the role of undergraduate research in encouraging intellectual, personal and professional development of undergraduate student researchers. Although the work of Seymour et al. revealed findings pertaining to attitudes toward graduate school and research, as well as confidence levels and other gains in skills, the number of engineering student participants was limited to a small number. Moreover, considering that in Dr. Seymour's study, "skills learned" was but one of several foci, it is essential to objectively assess learning outcomes in more depth such as focusing in the cognitive domain and also important to focus in engineering disciplines.

Most recently, one of the more extensive studies on assessing the benefits of undergraduate research experiences was conducted by SRI International, under contract to NSF [3-4]. The study involved a nationwide, large-scale evaluation of undergraduate research, encompassing STEM and social, behavioral, or economic sciences. With 3,400 individuals surveyed, their major findings showed that undergraduate research experiences were important in shaping career decisions and interests and tended to attract individuals who were already relatively highly motivated academically. Although this was a large-scale study, in which 582 engineering graduates (including participants and non-participants of undergraduate research) were surveyed, focused on inquiring about the benefits of undergraduate research, in-depth assessment of students' learning outcomes, skill gains, and the bodies-of-knowledge acquired were not assessed. Thus, although several studies have looked into the overall impact of undergraduate research, the bodies-of-knowledge and learning outcomes comprising of the countless ways in which students benefit and learn from being involved in research projects have been insufficient.

The purpose of this research is to focus on the learning outcomes and skills gained by engineering students as a result of participating in undergraduate research experiences. The specific **research questions** guiding this effort were:

1) What are engineering students' learning outcomes (cognitive, affective, social, and professional) and skill gains as a result of participating in undergraduate research experiences?
2) What variations (positive and negative) are discernable in the learning outcomes of diverse students groups (based on gender, ethnicity, academic level, etc.) during undergraduate research experiences?

In this paper, we will focus on research question one and future publications will address research question two. Of particular importance is how these experiences help to make better *engineers* leading to a broad range of successful career paths.

Herein, we developed and employed a survey instrument, National Engineering Students' Learning Outcomes Survey (NESLOS), derived from ABET criteria and extensive literature review, to allow students to self-assess their learning outcomes as a result of undergraduate research experiences. Survey item emphasis was placed on assessing knowledge and skills pertaining to but not limited to: (1) problem-solving, (2) writing and communication skills, (3) teamwork, (4) confidence gains, (5) organization and management skills, and (6) interest and engagement of project. Twenty-two summer REU sites across the nation were recruited, resulting to about 235 and 275 student participants, respectively for the pre- and post- surveys.

In this paper, we present key findings of what students learned and valued, present outcomes which should be better addressed during the experience, student career path goals, etc. The strength of the research design plan is that the results can be generalized to other REU sites and can be replicated across scientific disciplines and institutions at various levels and scales. These findings can aid REU site program directors and undergraduate research faculty advisors to improve their program and assessment efforts.

Methodology - Development and Administration of NESLOS

ABET criteria 3a-k challenges engineering institutions to produce graduates with professional as well as technical skills by outlining the desired attributes for graduating engineers. With this in mind, the development of NESLOS was guided by ABET's "3a through k" criteria which state that: "engineering programs must demonstrate that their graduates have:

(a) an ability to apply knowledge of mathematics, science, and engineering,
(b) an ability to design and conduct experiments, as well as to analyze and interpret data,
(c) an ability to design a system, component, or process to meet desired needs,
(d) an ability to function on multidisciplinary teams,
(e) an ability to identify, formulate, and solve engineering problems,
(f) an understanding of professional and ethical responsibility,
(g) an ability to communicate effectively,
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context,
(i) a recognition of the need for, and ability to engage in, lifelong learning,
(j) a knowledge of contemporary issues;
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.[5]"

Moreover, according to a recent NAE CASEE report, rigorous literature search revealed that the engineering education community desires four additional student outcomes [6]. Based on this report, an engineering graduate should also be able to demonstrate:

(l) an ability to manage a project, including a familiarity with business, market-related, and financial matters,
(m) a multidisciplinary systems perspective,
(n) an understanding of and appreciation for the diversity of students, faculty, staff, colleagues, and customers, and
(o) a strong work ethic.

Based on these fifteen learning outcomes, review of the literature and ABET-related sources, a survey instrument (NESLOS) was developed and included:

(a) about thirty technical learning outcomes closely linked to the ABET criteria,
(b) roughly twenty personal and professional learning outcomes pertaining to knowledge, skills, and interpersonal gains,
(c) several open-ended questions about the strengths and weaknesses of the undergraduate research experience, and
(d) general questions about the team, demographics, etc.

More details about NESLOS, including a list of some of the outcomes, are included in a previous ASEE publication, in which NESLOS was employed to assess students' learning outcomes during capstone design projects [7]. During this previous effort, both students and faculty were administered NESLOS and results revealed a strong correlation (75%) between students' self-ratings and faculty ratings of their students' learning. This finding revealed that NESLOS is valid as a self-assessment instrument. Most of the NESLOS items were based on a 5-point Likert scale. Item analysis and survey validation procedures revealed good reliability indexes (Cronbach's alpha coefficients) varying from 0.60 to 0.90. Twenty-two NSF REU sites nationwide were recruited to participate in the study. Most of these NSF REU sites had a 10-week duration over the summer. REU student participants were administered a web-based version of pre- and post- NESLOS instruments at the beginning and end of their undergraduate research experience. The pre- and post- NESLOS instruments were very similar, except for the post version including more items pertinent to the summative assessment of the experience. The survey instruments and administration were approved by the Institutional Review Board (IRB) of the Office of Research Compliance.

Participant Demographics

As mentioned previously, 22 NSF REU sites (focused on engineering-related research) nationwide were recruited to participate in this study. Administration of the pre- and post-NESLOS instruments took place using a web-based survey provider. There was a total of 235 students that participated in the pre-NESLOS instrument and 275 students in the post-NESLOS instrument. About 60% of these participants were engineering students and 40% were in the sciences (biology, physics, chemistry, mathematics, etc.). The percentage of female and male students was respectively 40% and 60%. Students' academic level was also assessed and it was found that about 60% were rising seniors, 30% rising juniors, 4% rising sophomores, 4% BS graduate/first year graduate students, and 2% rising freshman/high school. It is also important to keep in mind that all participants were paid during these summer undergraduate research experiences.

Results

Key findings and results from NESLOS are presented in this section. More specifically, we present students' high and low rated outcomes and compare their responses on the pre- and post-NESLOS instruments. It is important to keep in mind that the goal of the pre-survey was to get a measure of how helpful their academic and work experiences were to date in enabling them to achieve the specified outcomes. The post-survey, on the other hand, measured the extent to which the REU experience enabled them to achieve the specified outcomes. Comparison of pre and post responses would thus give a measure of the gains.

Overall Ratings of Learning Outcomes – Pre NESLOS Results

According to the pre-NESLOS responses, Tables 2 and 3 present the fifteen high-rated and fifteen low-rated outcomes prior to the REU experience starting. In asking the students "how helpful their academic and work experiences have been to date in enabling them to achieve each of the learning outcomes or skills," the percentages shown correspond to the students that rated the outcome with a 4 (helpful) and a 5 (very helpful).

Starting with Table 2, we observe that the high rated technical outcomes pertained to: conducting (or simulating) an experiment, applying engineering tools (e.g., software, lathes, oscilloscopes), and generating multiple concept alternatives. Whereas, the high rated professional and personal outcomes were: effectively managing conflicts that arise when working on teams, operating in the unknown (open-ended problems), communicating effectively, knowing what you want to do after graduation, understanding ethical responsibility, applying interpersonal skills, taking new opportunities for intellectual growth, recognizing intrinsic interest in learning/intellectual curiosity, gaining strong leadership skills, setting and pursuing own learning goals, recognizing connections between/within engineering and scientific disciplines, and gaining confidence.

Table 3 shows the outcomes that were least rated in the pre-NESLOS instrument. The technical outcomes that students assessed as not having gained in their academic and work experiences to data included: using feedback from an experiment, recognizing knowledge transfer between project and engineering courses (classroom), analyzing and interpreting data, designing a system, component, or process, designing an experiment, and understanding assumptions needed to solve problems. The professional and personal outcomes that were least rated were: improving organizational skills, engaging in critical self-assessment, recognizing the need to consult an expert, improving work ethic, recognizing the need for diverse perspectives, valuing the diversity of a team, recognizing the need for life-long learning, gaining leadership skills, and knowing what is needed to attain their goals after graduation.

Table 2: List of fifteen highest ranked learning outcomes (Pre-NESLOS). Ranking is based on the percentage of respondents who rated the outcome with 4 and 5.

High Ranked Learning Outcomes (Pre-NESLOS)	**Percent**
Effectively manage conflicts that arise when working on teams	90%
Conduct (or simulate) an experiment	90%
Operate in the unknown (open-ended problems)	90%
Communicate effectively with others	90%
Know what you want to do after graduation (get a job, go to graduate school, etc.)	87%
Apply engineering tools (e.g., software, lathes, oscilloscopes) in engineering practice	86%
Generate multiple design concept alternatives	86%
Understand the ethical responsibility associated with the engineering profession and also your design project	86%
Apply interpersonal skills in managing people	85%
Take new opportunities for intellectual growth or professional development	84%
Recognize intrinsic interest in learning/intellectual curiosity	84%
Gain strong leadership skills	84%
Set and pursue my own learning goals	83%
Recognize connections between/within engineering and scientific disciplines	82%
Gain confidence in myself	82%

Table 3: List of fifteen highest ranked learning outcomes (Pre-NESLOS). Ranking is based on the percentage of respondents who rated the outcome with 4 and 5.

Low Ranked Learning Outcomes (Pre-NESLOS)	Percent
Improve organizational skills	30%
Improve work ethic	32%
Use feedback from an experiment to improve solutions to an engineering problem	42%
Recognize knowledge transfer between senior design project and engineering courses (classroom)	53%
Engage in critical, reliable, and valid self-assessment	58%
Analyze and interpret data	58%
Recognize the need to consult an expert from a discipline other than my own when working on a project	63%
Design a system, component, or process to meet desired needs	65%
Recognize the need for diverse perspectives in solving engineering/scientific problems	65%
Value the diversity of a team (students, faculty, customers, etc.) leading to diverse talents and ways of thinking	66%
Design an experiment	66%
Recognize the need for life-long learning	67%
Gain leadership skills in managing team members and project tasks	68%
Know what you need to do to attain the goals you have for after graduation	69%
Understand assumptions needed to be made to solve your engineering design problem	69%

Overall Ratings of Learning Outcomes – Post NESLOS Results

In looking at the post-NESLOS responses, in which students self-assessed their summer undergraduate research experience, Table 4 shows the outcomes that were highly rated/ranked. The technical outcomes that students assessed highly included: understanding assumptions needed to solve problem, using evidence to draw conclusions or make recommendations, analyzing and interpreting data, conducting (or simulating) an experiment, as well as identifying and defining problems for which there are engineering solutions. The professional and personal outcomes that were highly rated were: communicating effectively, conveying ideas verbally and in formal presentations, taking new opportunities for intellectual growth or professional development, recognizing the need for life-long learning, gaining confidence in myself, setting and pursuing own learning goals, conveying technical ideas in formal writing and other design documentation. Two other important outcomes that were highly rated pertained to "knowing what you *want* to after graduation" and "knowing what you *need* to do after graduation." These two outcomes illustrate how the undergraduate research experience allowed many students to either clarify or validate their career goals after graduation.

Table 4: List of fifteen highest ranked learning outcomes (Post-NESLOS). Ranking is based on the percentage of respondents who rated the outcome with 4 and 5.

High Ranked Learning Outcomes (Post-NESLOS)	Percent
Communicate effectively with others	93%
Convey ideas verbally and in formal presentations	93%
Take new opportunities for intellectual growth or professional development	90%
Recognize intrinsic interest in learning/intellectual curiosity	88%
Understand assumptions needed to be made to solve your engineering design problem	87%
Know what you need to do to attain the goals you have for after graduation	86%
Use evidence to draw conclusions or make recommendations	86%
Analyze and interpret data	86%
Recognize the need for life-long learning	86%
Gain confidence in myself	85%
Set and pursue my own learning goals	84%
Convey technical ideas in formal writing and other design documentation	84%
Conduct (or simulate) an experiment	84%
Know what you want to do after graduation (get a job, go to graduate school, etc.)	84%
Identify and define problems for which there are engineering solutions	84%

As important as it is to present the learning outcomes that were most valued by the REU students, it is also important to present the least rated outcomes because it is from this list that we can assess what changes should be made in order to improve the experience and the learning. Table 5 shows the outcomes that were ranked low. From this list, the technical outcomes that were rated low include: creating and following a budget, applying technical codes and standards, generating multiple concept alternatives, applying engineering skills (e.g., experimentation, machining, programming), creating and following a timeline, identifying potential ethical issues, understanding ethical responsibility, and understanding the impact of the research in a societal and global context. As for the professional and personal outcomes, the following were ranked low: gaining leadership skills, effectively managing conflicts that arise when working on teams, applying interpersonal skills, gaining strong leadership skills, and working in teams where knowledge and ideas from many engineering disciplines must be applied.

Table 5: List of fifteen highest ranked learning outcomes (Post-NESLOS). Ranking is based on the percentage of respondents who rated the outcome with 4 and 5.

Low Ranked Learning Outcomes (Post-NESLOS)	Percent
Follow a budget when managing a project	19%
Create a budget when managing a project	20%
Identify potential ethical issues and dilemmas in your research project	43%
Apply technical codes and standards	47%
Understand the ethical responsibility associated with the engineering profession and also your research project	49%
Gain leadership skills in managing team members and project tasks	50%
Effectively manage conflicts that arise when working on teams	51%
Apply interpersonal skills in managing people	53%
Gain strong leadership skills	56%
Generate multiple design concept alternatives	63%
Apply engineering skills (e.g., experimentation, machining, programming) in engineering practice	64%
Follow a timeline when managing a project	66%
Create a timeline when managing a project	68%
Understand the impact of your research in a societal and global context	69%
Work in teams where knowledge and ideas from many engineering disciplines must be applied	69%

Additional skills and learning outcomes that students gained during the undergraduate research experience were measured in the form of an open-ended question in NESLOS. Students' responses to this question were:

- Patience
- Applying my knowledge and expand it in areas of which I had no previous knowledge
- Ability to take on projects and tasks just outside of my comfort zone
- Programming skills
- Interconnectedness of research - no one person can move a discipline forward without the input, help, and support of the team they work with
- Importance of networking
- The ability to identify logistical problems and solve them to avoid delays.
- Database search and laboratory etiquette
- Friendships, dedication, and compromise
- Self-motivation
- Working with various high tech tools and equipment
- Sensitive to time frame/deadlines
- Improving time management skills
- I learned what it takes to be a scientist or an engineer.

Comparison of Pre and Post NESLOS Results

Chi-square analysis revealed statistically significant differences in students' pre and post ratings of learning outcomes. Some of the most significant differences are summarized in Table 6, which includes a list of 18 learning outcomes. Of these, ten (corresponding to 56%) were rated higher in the post survey, suggesting that these are some of the outcomes which resulted to learning gains and can be attributed to the undergraduate research experience. These ten outcomes pertain to: improving organizational skills, improving work ethic, using feedback from an experiment, analyzing and interpreting data, recognizing knowledge transfer between research project and engineering courses, recognizing the need for life-long learning, understanding assumptions needed to solve engineering problems, knowing what is needed to attain goals for after graduation, conveying ideas verbally and in formal presentations, and engaging in critical self-assessment.

Table 6: List of learning outcomes that revealed the highest significant percent differences comparing pre and post survey responses. Percentages shown are based on the number of respondents who rated the outcome with a 4 or a 5. [chi-square analysis, $^{**}p<0.001$]

List of Learning Outcomes	**Pre**	**Post**	**% Diff**
Improve organizational skills	30%	74%	43% **
Improve work ethic	32%	74%	43% **
Use feedback from an experiment to improve solutions to an engineering problem	42%	84%	41% **
Effectively manage conflicts that arise when working on teams	90%	51%	-40% **
Understand the ethical responsibility associated with the engineering profession and also your research project	86%	49%	-37% **
Apply interpersonal skills in managing people	85%	53%	-32% **
Apply technical codes and standards	79%	47%	-32% **
Identify potential ethical issues and dilemmas in your design project	71%	43%	-29% **
Analyze and interpret data	58%	86%	28% **
Gain strong leadership skills	84%	56%	-27% **
Generate multiple design concept alternatives	86%	63%	-24% **
Recognize knowledge transfer between research project and engineering courses (classroom)	53%	73%	20% **
Recognize the need for life-long learning	67%	86%	19% **
Gain leadership skills in managing team members and project tasks	68%	50%	-18% **
Understand assumptions needed to be made to solve engineering problems	69%	87%	18% **
Know what you need to do to attain the goals you have for after graduation	69%	86%	17% **
Convey ideas verbally and in formal presentations	78%	93%	15% **
Engage in critical, reliable, and valid self-assessment	58%	73%	15% **

Future Career Goals

Part of NESLOS was the assessment of participants' plans after graduation. The following table summarizes the results from the NESLOS question "What are your plans after graduation?" and presents overall responses during the pre and post surveys. As can be seen, no significant differences exist between pre and post NESLOS responses. This suggests that students recruited and selected to participate in REU experiences are students that already have plans to attend graduate school and the REU experience served to validate this career path.

Table 7: Summary of responses for participants' plans after graduation.

What are your plans after graduation?	**NESLOS**	
	Pre (N=275)	**Post (N=235)**
Industry - In an engineering/scientific occupation	10%	9%
Industry - Outside an engineering/scientific occupation	1%	0%
Graduate School - In an engineering/scientific discipline	76%	76%
Graduate School - Outside an engineering/scientific discipline	3%	4%
Other	10%	11%
TOTAL	100%	100%

Overall Experience Ratings

Overall, students highly valued their REU experience. When asked to rate how well they agreed with the following statements - "overall, I am satisfied with my undergraduate research experience" – 93% of the participants "agreed" and "strongly agreed" with the statement. Similarly, when asked to rate how well they agreed with "overall, the experience is a valuable learning experience," 98% of the participants "agreed" and "strongly agreed" with the statement.

Discussion and Conclusions

In this paper, we presented key findings from a quantitative study designed to assess engineering students' learning outcomes as a result of participating in undergraduate research experiences. Having recruited 22 NSF REU sites running over a 10-week summer session, we collected data from 235 students during the pre-NESLOS administration and 275 students during the post-NESLOS administration. Overall, the experience was highly valued by the students as a very important learning experience which allowed them to learn "what it takes to be a scientist or an engineer" as one student described.

Results from both the pre- and post- NESLOS instruments revealed students' high and low ranked learning outcomes. From the pre-survey, designed to measure the extent to which academic and work experiences enabled students to achieve the specified outcomes, we observed that students highly rated a few technical outcomes relevant to conducting an experiment and applying engineering tools, but mainly rated the professional and personal outcomes more highly. These were more focused on skills gained as a result of working and dealing with teams and personal growth. It is from the outcomes that were least rated/ranked during the pre-survey that we can learn from and improve the academic experience. These included: (1) using feedback from an experiment and analyzing data, (2) recognizing knowledge transfer between project and engineering courses (i.e. using more real-world problems in coursework), (3) designing an experiment, a system, component, or process, (4) improving organizational skills and work ethic, (5) engaging in critical self-assessment, (6) recognizing the need to consult an expert, (7) recognizing the need for diverse perspectives, (8) recognizing the need for life-long learning, and (9) gaining leadership skills.

From the post-survey, which measured the extent to which the undergraduate research experience enabled the students to meet the specified outcomes, results shows that students highly ranked problem-solving, analytical, and experimentation skills such as: understanding assumptions needed to solve problem, using evidence to draw conclusions or make recommendations, analyzing and interpreting data, conducting (or simulating) an experiment, as well as identifying and defining problems for which there are engineering solutions. High ranked professional and personal outcomes were: communicating effectively, conveying ideas verbally and in formal presentations, taking new opportunities for intellectual growth or professional development, recognizing the need for life-long learning, gaining confidence in myself, setting and pursuing own learning goals, conveying technical ideas in formal writing and other design documentation.

Looking at the list of least-rated outcomes during the REU experience, we observe that students wanted more experience in: creating and following a budget, generating multiple concept alternatives, applying engineering skills (e.g., experimentation, machining, programming), creating and following a timeline, identifying potential ethical issues, understanding ethical responsibility, and understanding the impact of the research in a societal and global context. Also, the professional and personal outcomes that were ranked low were: gaining leadership skills, effectively managing conflicts that arise when working on teams, applying interpersonal skills, gaining strong leadership skills, and working in teams where knowledge and ideas from many engineering disciplines must be applied. Looking at these outcomes, it appears that the REU experience could be enhanced if more project management skills were incorporated as well as more team-based activities where the undergraduate researchers can interact could be introduced. Even though laboratories, which are filled with graduate students and faculty, is a group setting, research is an activity that often deals with more independent tasks and analysis. Interestingly, this is picked up from the students' responses and more team-based activities among the undergraduate researchers would add to the experience.

Measured in the form of open-ended questions in NESLOS, additional skills that students gained during the undergraduate research experience were patience, programming skills, recognizing the interdisciplinarity of research, networking, literature searching and laboratory etiquette, social interactions, working with state-of-the-art tools and equipment, improving time management skills, and most importantly learning how to be a researcher.

Another significant finding from this study was that no significant differences existed when comparing students' pre and post responses in terms of career goals. This suggested that students recruited and selected to participate in REU experiences were students that already had plans to attend graduate school and the REU experience simply served to validate their aspirations for graduate school. Granted, the REU was a valuable learning experience for them to learn what it means to be a graduate students and what it means to do research.

Although there are limitations to this study, many of which can be solved by incorporating qualitative methods, such as interviews and focus groups, these are important findings, which can aid engineering departments, REU site directors and coordinators, and faculty advisors to improve undergraduate research experiences and assessment efforts.

Acknowledgements

The authors would like to thank the REU site directors, coordinators, assessment personnel, and students that participated in this study. Also, we would like to thank CASEE for supporting Dr. Pierrakos as a NAE CASEE Postdoctoral Fellow, and graduate student Shankar Arul, who assisted us with the analysis.

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