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Understanding Cooperative Education and Internships: The Influence on Engineering Students’ Problem Solving Skills

Abstract

Cooperative education is a form of experiential education that allows students to gain experience in their profession. This quantitative study will utilize a national dataset to examine the influence of cooperative education on engineering students’ perception of their engineering thinking skills. The objective of this study is to answer the following question: 1) does experience in cooperative education or internship program influences students’ self-perceptions of their engineering problem-solving skills? The statistical models controlled for academic ability, social economic status, engineering discipline, time spent in a design competition, urbanization of an institution, and institution’s highest degree awarded.

The analysis from a national dataset of 2004 seniors (n=4461 from 39 institutions) suggests that students who spent more time in a cooperative education program are better at ensuring that a process or product meets a variety of technical and practical criteria and comparing and judging alternative outcomes than students who have little or no experience in a co-op.

Introduction

The National Academy of Engineering is concerned with both the pipeline of engineering students and the characteristics needed by the successful engineer of the future. According to the NAE report, The Engineer of 2020: Visions of Engineering in the New Century, these characteristics include strong analytical skills; practical ingenuity; creativity; communication skills; principles of business and management; leadership; high ethical standards; professionalism; dynamism; agility; resilience; flexibility; and life-long learning. The report illustrates the engineering community’s commitment not only to increase the number of engineering graduates, but also to graduate competent engineers who will succeed in the global economy of 2020. The urgency to prepare the Engineer of 2020 has been a community effort as the Accreditation Board for Engineering and Technology (ABET) has shifted its accreditation criterion from institutional resources (e.g., faculty credentials and library size) to student learning outcomes. Many of the Engineer of 2020 skills align with ABET’s criteria for student learning outcomes.

The emphasis on technical knowledge and professional skills such as teamwork and communication in the Engineer of 2020 learning outcomes and ABET criteria suggest that learning experiences which stress these kinds of activities will be more effective for developing the necessary engineering workforce. Cooperative education (co-op) or internship programs provide off-campus work experiences that engage students in solving authentic engineering problems that elucidate textbook problems seen in the classroom. For example, if a textbook chapter focuses on electromagnetic fields, the problem sets from that chapter will deal with this topic (and not some other engineering topic such as optics). The problem’s scope (i.e., the issue is related to electromagnetic fields) is defined for the student. Thus, in working textbook problems, students may not develop the flexibility in problem identification to solve real-world
problems. On the other hand, co-op students and interns assigned to a real-world task, such as designing a new computer hardware component, must learn to identify the most salient issues related to circuit devices, design, cost, and hardware compatibility in order to complete the assignment. Working on authentic tasks from industry may help students develop the flexibility and confidence to solve engineering problems. The objective of this study, then, is to answer the following question: 1) does experience in cooperative education or internship program influences students’ self-perceptions of their engineering problem-solving skills?

Cooperative Education Research

Research on the benefits of engineering students’ participation in a co-op suggests that co-op students have more job interviews\(^i\), higher starting salaries\(^vi, vii, viii\) and higher grade point averages\(^ix, x\) compared to students who do not participate in these programs. Friel surveyed 691 cooperative education directors who reported that co-op students are perceived to be more professional, more skilled problem solvers, better able to manage projects, and more technically knowledgeable than students without cooperative education experience\(^xi\). Pierrakos, Borrego, and Lo discovered that co-op students perceive their co-op experiences as helpful in aiding their development of problem-solving skills\(^xii\).

A major of both the Friel\(^xiii\) and Schuurman et al.\(^xiv\) analyses is the lack of statistical control for student academic ability, which potentially confounds the effects of student ability and cooperative education participation. Additionally, much of the research on cooperative education is descriptive, summarizing the effects of co-ops on student learning outcomes. For example, the percentage of employers who say cooperative education students have higher problem-solving ability than students who do not participate in a co-op. This type of analysis provides evidence that suggests co-op students’ problem-solving skills improve, but provides little to no understanding of how this skill is developed in the co-op work setting. Consider the complexity of a skill like problem-solving in engineering, which includes elements such as applying fundamentals to new problems, breaking down complex problems to simpler ones, knowing when to use a formula, algorithm or other rule, ensuring that process or product meets a variety of technical and practical criteria, and comparing and judging alternative outcomes\(^xv\). Existing studies of cooperative education have not examined aspects of problem-solving that are enhanced by the experience. This study will fill that gap.

Engineering Problem-Solving Skills

Mayer and Wittrock define problem-solving as “the cognitive process directed at achieving a goal when no solution is obvious to the problem solver (p. 287).\(^xvi\)” This definition suggests that problem-solving has four characteristics. Problem-solving is 1) cognitive (i.e., it is an internal process that occurs in the person’s mind), 2) process-oriented (the manipulation of knowledge), 3) goal-directed (i.e., the process is guided by the person’s goals), and 4) personal (dependent on the person’s skills and knowledge). According to Donald \(^xvii\), the problem-solving process in engineering involves the following thinking skills:

a) Breaking down complex problems to simpler ones
b) Applying fundamentals to new problems
c) Identifying critical variables, information, and/or relationships involved in a problem
d) Knowing when to use a formula, algorithm, or other rule  

e) Recognizing and understanding organizing principles (laws, methods, rules, etc.) that underlie problems  

f) Developing a course of action based on the understanding of a whole system  

g) Drawing conclusions from evidence or premises  

h) Ensuring that a process or product meets a variety of technical and practical criteria  

i) Comparing and judging alternative outcomes  

j) Develop learning strategies that I can apply in my professional life  

For students to succeed in the engineering profession, they will need to develop their problem-solving ability to a proficient level before graduation.  

If we apply Mayer and Wittrock’s xviii definition of problem-solving to Donald’s xix engineering problem-solving process, we would expect an engineer to break a complex problem, such as how to design and build a bridge (thinking skills a, above) down into sub-goals and identify the critical variables, information, or relationships involved in the problem (c). This cognitive process of simplifying the problem occurs within a person’s mind. An engineer will address the situation by applying her knowledge in mathematics, physical sciences, and structural engineering (b) to formulate a range of solutions that will meet the desired needs and safety specifications for the bridge (f and h). In other words, the manipulation of information is goal-directed. The ease of this process is dependent on the engineer’s level of expertise in content knowledge (declarative knowledge) and procedural knowledge (i.e., she knows when to use a particular algorithm, formula or process) (d and e). Evaluation of the process and judgments of alternative outcomes (i) may be influenced by the engineer’s personal skills and bias on whether the project is a success or not (i.e., maybe the bridge met the functional specifications but failed from an aesthetic perspective).  

Self-Perception of Problem-Solving Skills  

Bandura's self-efficacy theory postulates that an individual’s confidence rises when he has mastered a skill through experiencexx. Self-efficacy studies in STEM fields involving students in chemistry xxii, computer science xxii, engineeringxxii, xxiv and mathematicsxxv have found a mastery experience to be influential in a person's self-efficacy. These findings are not limited to STEM fields as Usher and Pajares xxvi, in a review of the literature, found a mastery experience to be the most prevalent source of developing a person's self-efficacy. Engineering students, thus, who had little success in solving problems are likely to perceive themselves as weak problem-solvers; while, students who had success in solving problems are likely to perceive themselves as good problem-solvers.  

Understanding students' perceptions of their efficacy in different domains is important, because Zusho et al. xxvi, Hutchison et al. xxviii, and Pajares and Miller'sxxix also found evidence to suggest that self-efficacy is a good predictor of achievement. Self-efficacy, then, can serve as a reasonable proxy for gauging problem-solving ability because individuals who are more confident in their ability are also more likely to perform better than individuals who are less confident in their ability.
Methods

The dataset analyzed for this study was developed for the Engineering Change (EC2000) project sponsored by ABET and the National Science Foundation (Grant No. EEC-9812888) and conducted by faculty members in the Center for the Study of Higher Education (CSHE) at the Pennsylvania State University. This nationally representative database contains 4,461 survey responses from engineering seniors of the class of 2004 in seven engineering disciplines (aerospace, chemical, civil, computer, electrical, industrial, and mechanical) in 39 accredited engineering institutions. The sample of colleges and universities included institutions classified as Doctoral, Master’s, and Bachelors’ and Specialized Institutions.

For this analysis, I define cooperative education programs to include internships, because both experiences provide students with opportunities to apply the knowledge and skills learned in the classroom to a work setting. Students in internships, however, are only engaged in the work setting for a single semester or summer, whereas co-op students work for multiple semesters, often with the same employer, so a comparison of the two kinds of experiences is warranted.

Design

Dependent Measures. The Survey of Graduating Seniors (for a copy of the survey, see http://www.ed.psu.edu/educ/ec2000/survey-instruments/student-survey) incorporated measures of eleven learning outcomes that all accredited undergraduate programs in engineering must address as specified by the Accreditation Board for Engineering and Technology (ABET). The survey questions were developed in an iterative process, beginning with a literature review of existing instruments that assess these learning outcomes and including consultations with Penn State engineers (see Volkwein, Lattuca, Terenzini, Strauss, & Sukhbaatar for a description of the instrument development process). The survey was then pilot tested to gauge the internal consistency of the learning outcome measures.

The ten dependent variables that measure problem-solving skills are 2004 seniors’ responses to a set of survey items that form the engineering thinking skills factor (Table 1). Seniors rated their abilities on each of the eighteen items on a five-point scale (where 1 = No Ability, 2 = Some Ability, 3 = Adequate Ability, 4 = More than Adequate Ability, and 5 = High Ability). The engineering thinking skills factor, which corresponds to Donald’s problem-solving process, has a Cronbach’s alpha of .94.

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<th>Table 1: Items Examined from the Engineering Change (EC2000) Project</th>
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Independent Measures. Seniors’ self-reports of the number of months spent in cooperative education or internships are the independent variables in the analysis. The sample includes 1,803 (40.42%) students who did not participate in a co-op or internship; 743 students (16.66%) who spent 1-4 months in a co-op or internship; 699 (15.67%) students who spent 5-8 months in a co-op or internship; 595 (13.34%) students who spent 9-12 months in a co-op or internship; and 621 (13.92%) students who spent more than 12 months in a co-op or internship.

When examining the influence of cooperative education on the three focal outcomes, I controlled seniors’ academic ability and socioeconomic status (SES) in my statistical models. To control for academic ability, seniors’ self-reported college grade-point-average (GPA) is included as an explanatory variable in the model. Seniors’ college GPA was recorded into the following categories: 3.50-4.00 (A- to A), 3.00-3.49 (B to A-), 2.50-2.99 (B- to B), 2.00-2.49 (C to B-), 1.50-1.99 (C- to C), and Below 1.49 (Below C-). I used seniors’ self-reports of their parents’/guardians’ annual family income as a proxy for socioeconomic status. Seniors’ self-reported their family’s annual income into the following categories: Below $20,000, $20,001-$30,000, $30,001 – $50,000, $50,001 - $70,000, $70,001 - $90,000, $90,001 - $110,000, $110,001-$130,000, $130,001- $150,000, and More than $150,000. Seniors’ major (aerospace, chemical, civil, computer, electrical, industrial, and mechanical) and time spent in design projects and competitions beyond class requirements were also included as explanatory variables in the model to control for the influence of classroom experiences and extracurricular activities.

In my models, I also controlled for institutional characteristics such as Carnegie classification and urbanization. The sample included 27 Research Extensive, three Research Intensive, five Master’s and four Bachelor’s institutions. Of the 39 institutions, 12 are located in a large city, nine in a midsize city, 12 in a small city, two in a large suburb, one in a midsize suburb, one is on town fringe, one is classified as town distant, and 1 is classified as rural fringe. The U.S. Census Bureau’s Population Division assigned the urbanization codes to the geographic regions in which the institution is located.

Analysis

With ordinal dependent variables, the eighteen items that form the independent measures are fitted with logit models to examine the relationship between the number of months participating in an internship or co-op and seniors’ reports of their ability on each of the ten items within the Engineering Thinking Skills factor (Table 1).
The items within the focal outcomes are ordinal and cannot be analyzed using linear regression models due to violation of the normality assumption. Ordinal dependent variables can be analyzed utilizing logit models. Two kinds of logit models will be used in this analysis: Proportional-odds cumulative logit model and baseline-category logit model. Using a multinomial logistic model instead of four binary logistic regression models allows the researcher to control for experiment-wise error, which is analogous to utilizing an analysis of variance (ANOVA) over \( n \) number of independent t-tests.

**Baseline-category Logit Model**

A baseline-category logit model (Equation 1) is used to examine the influence of time spent in an internship or cooperative education. A baseline-category logit model is a subset of multinomial logistic regression models that estimates the likelihood of being in one category (the baseline) compared to another category for all possible combinations with the baseline category. Since the dependent variables for this study have five possible responses, four simultaneous logits will be examined with “High Ability” as the baseline category.

**Equation 1: Baseline-category Logit Model for Analyzing Scale Items**

\[
\log \left( \frac{P(\text{No Ability})}{P(\text{High Ability})} \right) = \beta_{10} + \beta_{11} \cdot \text{Co-op} + \beta_{1x} \cdot \text{Control Variables}
\]

\[
\log \left( \frac{P(\text{Some Ability})}{P(\text{High Ability})} \right) = \beta_{20} + \beta_{21} \cdot \text{Co-op} + \beta_{2x} \cdot \text{Control Variables}
\]

\[
\log \left( \frac{P(\text{Adequate Ability})}{P(\text{High Ability})} \right) = \beta_{30} + \beta_{31} \cdot \text{Co-op} + \beta_{3x} \cdot \text{Control Variables}
\]

\[
\log \left( \frac{P(\text{High Ability})}{P(\text{High Ability})} \right) = \beta_{40} + \beta_{41} \cdot \text{Co-op} + \beta_{4x} \cdot \text{Control Variables}
\]

If the internship/cooperative education variable is significant, the parameter estimates for each of the dummy variables for this model will be analyzed to estimate the odds ratio of being in the baseline category (High Ability) as opposed to the comparison category. The odds ratios for this model will allow comparisons between varying levels of time spent in an internship and/or cooperative experience and one of the eighteen items comprising the focal outcomes (Table 1). For example, the analysis will provide information on whether students who spent more than 12 months in cooperative education or internships perceive their ability higher than students who only participate 1-4 months.

**Proportional-odds Cumulative Logit Model**

For some items within the focal outcomes, a proportional-odds cumulative logit model is a better model than a baseline-category logit model because it satisfies the equal-slopes assumption. A benefit of using proportional logit models is that there are fewer parameters to estimate than a baseline-category logit model, since the proportional-odds cumulative logit model assumes that the slopes for each variable are equal across the different logit equations (Note \( \beta \)'s are equal in Equation 2).
This model (Equation 2) describes the log-odds of two cumulative probabilities: the likelihood of being in the category or below compared to the likelihood of being in the category above. For example, the model will examine the probability of the student rating his ability as high versus his ability in any of the other lower categories (more than adequate ability, adequate ability, some ability and no ability). The cumulative logit for this model is coded such that the log-odds is the likelihood of being in the category or above versus the likelihood of being in the category below.

Equation 2: Proportional-odds Cumulative Logit Model for Analyzing Scale Items

\[
\begin{align*}
\log \left( \frac{P(\text{High Ability})}{P(\text{High Ability} + > \text{Adequate Ability})} \right) &= \alpha_1 + \beta_1 \times \text{Co-op} + \beta_2 \times \text{Control Variables} \\
\log \left( \frac{P(\text{Adequate Ability} + > \text{Some Ability} + \text{No Ability})}{P(\text{Adequate Ability} + > \text{Some Ability} + \text{No Ability})} \right) &= \alpha_2 + \beta_1 \times \text{Co-op} + \beta_2 \times \text{Control Variables} \\
\log \left( \frac{P(\text{High Ability} + > \text{Adequate Ability} + \text{Some Ability})}{P(\text{No Ability})} \right) &= \alpha_3 + \beta_1 \times \text{Co-op} + \beta_2 \times \text{Control Variables}
\end{align*}
\]

For the proportional-odds ratio logit models developed in this study, a positive odds ratio indicates that seniors are likely to rate their ability higher by the odds ratio value for each one-unit increase in the explanatory variable (time spent in a co-op or internship). For example, if \( \beta_1 \) is greater than one, this would suggest that students spending more time in a cooperative education will more likely to rate their ability in a high category (e.g., high ability) than in a category below (more than adequate, adequate, some, or no ability).

**Findings**

The following ten items form the engineering thinking skills scale: 1) Break down complex problems to simpler ones; 2) Apply fundamentals to problems that I haven’t seen before; 3) Identify critical variables, information, and/or relationship involved in a problem; 4) Know when to use a formula, algorithm, or other rule; 5) Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems; 6) Draw conclusions from evidence or premises; 7) Develop a course of action based on my understanding of a whole system; 8) Ensure that a process or product meets a variety of technical and practical criteria; 9) Compare and judge alternative outcomes; and 10) Develop learning strategies that I can apply in my professional life.

Table 2 displays the distributions of participants’ answers to each of the nine items in the engineering thinking skills scale. The majority (more than 90%) of the seniors reported their ability to be adequate or greater for each of the nine items in the engineering thinking skills scale.
The multi-nominal logit models examined whether time spent in a co-op or internship influenced students’ perceptions of their abilities for each item within the Engineering Thinking Skills scale. In total, ten multi-nominal logit models were developed for this study. Time spent in a co-op or internship variable was significant at an alpha of .05 for the following items:

- Ensure that a process or product meets a variety of technical and practical criteria (p-value = .0288)
- Compare and judge alternative outcomes (p-value = .0031)

Significance at a less stringent alpha suggests that time spent in a co-op or internship variable had a moderate influence on students’ ability. For the following items, time spent in a co-op or internship variable was not significant at an alpha of .05 but was significant at an alpha of .10.

- Develop a course of action based on my understanding of a whole system (p-value = .0550)

The majority of the odds ratios were greater than one for the multi-nominal logit models, providing evidence that as time spent in a co-op or internship increased, students’ perceptions of their abilities also increased. For example, the more time spent in a co-op or internship, the more
likely a student was to rate his ability to understand essential aspects of the engineering design process higher than a student who spent less time in a co-op or internship.

The main effects for the following skills were not significant, but some of the odds ratios estimates were significant and greater than one when examining the probability of a student rating himself adequate ability to high ability and the more than adequate ability to high ability models.

- Draw conclusions from evidence or premises (p-value = .3513)
These odds ratios show that as time spent in co-op or internship increased, the more likely a student was to rate himself as having high ability compared to adequate ability or more than adequate ability.

The time spent in co-op or internship variable for the following items was not significant, suggesting that time spent in a co-op or internship has no influence on a student’s perception of her ability to:

- Break down complex problems to simpler ones (p-value = .5571)
- Apply fundamentals to problems that I haven’t seen before (p-value = .7715)
- Develop learning strategies I can apply in my professional life (p-value = .1688)
- Identify critical variables, information, and or relationship involved in a problem (p-value = .3745)
- Know when to use a formula algorithm or other rule (p-value = .5598)
- Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems (p-value = .6756)

Conclusion

The relative homogeneity in students’ self ratings in this sample (which is representative of the national population) suggests that engineering programs are preparing students to be fairly competent problem-solvers even without co-op or internships. Spending time in a co-op or internship, however, while not a necessary curricular component in producing competent engineers, enhances certain problem-solving skills. Thus, students with co-op or internship experiences perceive themselves to be more competent problem-solvers than students with no co-op or internship experiences.

The impact of co-op or internship experience on these items should not be overstated because the models developed had pseudo r-square values between .06 and .10. These results were not unexpected as the majority of the engineering seniors in 2004 rated their ability as either more than adequate ability or high ability on the items.

Future research though should, then, focus on how and why work experiences allow engineering students to have a higher perception of their problem-solving skills than those with no work experience. One hypothesis is that the experience gained may provide the context needed for students to understand and apply engineering equations, possibly making them competent problem solvers. For example, a student may not begin to understand the importance of power until he designs a chip that overheats and melts a circuit board. The lesson learned from not accounting for power might help this student become a better chip designer in the future.
Findings from these types of studies may provide suggestions on how the curriculum can be modified to help enhance engineering students’ problem-solving skills.

Bibliography


