AC 2011-1545: HOW DOES THE TRANSFER OF CONSTRUCTION ENGINEERING EXPERTISE IMPACT THE COGNITION AND WORK PRACTICE OF THE ENGINEERS IN THE CONSTRUCTION WORK FORCE?

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Introduction

The efficient delivery of capital infrastructure projects is fundamental for the proper development of the US and thus for the safety and rapid prosperity of its society. However, most engineers in the construction workforce lack the understanding of basic construction principles and skills and hence cannot apply them when delivering capital infrastructure projects. This lack of formal construction expertise among engineers is a direct consequence that the discipline of construction engineering was only regulated by The National Council of Examiners for Engineering and Surveying (NCEES) as a formal field of professional practice in 2008 (NCEES 2008[1]). This late recognition of construction engineering as a field of professional practice has historically resulted in a minimum production of construction-educated engineers. Thus, a vast majority of the engineers in the construction workforce has a background in an engineering discipline other than construction, such as civil, electrical, chemical, mechanical, or instrumentation, among others. Even though no data on this issue has been published, one can presume that this lack of construction expertise among the engineers in the construction workforce has a significant negative toll on the cost, schedule, and quality of the built infrastructures. Indeed, construction is a multi-billion and strong industry that generates 15% of the US Gross Domestic Product. Despite of the low economic environment, though, the number of engineers employed by the US construction firms is projected to steadily increase in the coming years. Specifically, the number of engineers employed by owner and contractor organizations will reach a maximum of 645,000 by 2018, a number that represents a 17% growth from 2008 (BLS 2010[2]). Such forecasted growth in the number of engineers employed by construction firms magnifies the necessity to provide solid outlets for their continuous education.

Indeed, the engineers in the construction force cannot typically access traditional education outlets, such as those provided by US colleges and universities. The physical presence of most engineers is constantly required at remote, frequently offshore, project sites (NAE 2004[3]; ASCE 2006[4]), and precludes their enrollment in traditional face-to-face programs. In an attempt to educate their engineers, some owner and contractor organizations have opted to develop their own training programs in basic construction principles and skills with the overreaching objective to enhance the performance of both their capital delivery projects and as an organization.

Based on these premises, this study represents a primary step to investigate the answer to fundamental questions about the need to transfer construction engineering principles and skills to practicing engineers in the construction workforce. For instance, would such transfer of knowledge have a positive impact on practicing engineers? If so, would the transfer of construction engineering knowledge increase the ability of the engineers to understand the construction processes that they lead? Would such knowledge affect their work practice? In order to answer these and other fundamental questions, this study has investigated the impact of an intensive training program in the discipline of construction engineering on the cognition and work behavior of Supervising Discipline Engineers (SDE) affiliated with a large U.S. design and construction organization. To the best of our knowledge, a few efforts have already tried to unveil the impact of construction interventions in practicing engineers (Thomas 1999[5]; Thomas 2000[6]; Ibbs 2003[7]; Riley 2005[8]). However, these studies were constrained to analyze the influence of training efforts specifically designed for the completion of a set of field activities as opposed to the education of engineers in basic construction principles and skills.

The rest of the sections in this paper detail and discuss the objectives of this study, the educational intervention, and the self-assessment data collection process. Then, the intervention results and conclusions discuss and summarize the findings of this study.

Objectives

This study aims to evaluate the impact of an educational intervention in the construction principles and skills of a sample of non-construction engineers affiliated with a large design and contractor organization. In addition, it aims to assess the long-term influence of the training intervention in the work practice of the engineers.

Training intervention

In order to satisfy these objectives, this study tackles a quasi-experimental research method (Shadish et al. 2002[9]). The quasi-experimental approach fits with the assignment of a convenience sample of engineers for the instructional intervention. The findings of any of such quasi-experimental study, though, are still generalizable to an entire population (Shadish et al. 2002[9]; de Vaus 2002[10]). Thus, we assessed the impact of an intensive training intervention in the knowledge and work practice of a sample of engineers within a large Engineering-Procurement-Contractor (EPC) firm. A board of advisors was brought together with senior managers from the firm for the intensive training intervention in order to: 1) define the goals of the training intervention; 2) oversee the implementation of the intervention; and 3) provide feedback to the firm based on the results of this study. The affiliation of the board members with distinct departments within the organization aimed at ensuring a diversity of perspectives and opinions that could enrich the training program. From the board members' point of view, the training intervention was a fundamental educational tool both to acquaint an engineer with basic construction principles and skills and also to provide the engineer with a critical perspective on the field work within his/her own discipline –a discipline that, as mentioned below, was different from construction engineering. In addition, the board aimed at the alignment of the engineers' expertise in construction around a common set of principles and skills that could favor their utilization across engineering disciplines.

A sample of 50 SDE engineers was selected by the board to attend the workshop based on their sustained record of work proficiency and on the likelihood of their promotion to higher management positions in the coming future. In a construction project, each SDE engineer was responsible for all the construction work in his/her own discipline. The amount of work experience of the sampled engineers ranged from 2 to 28 years, and the distribution of both their background across distinct disciplines (i.e. mechanical, electrical, piping, structural, instrumentation and control, and process) and work locations was carefully reviewed by the board in order to avoid any bias in the sample that could affect the findings of this study.

Three modules defined the training intervention. The modules were separately instructed at different locations in a four months period and covered, in this order, the following topics: front end planning, project execution methods, and project completion and team dynamics. Table 1 details the instructed material. Each module was taught by a different professor from The Department of Civil, Construction, and Environmental Engineering at the University of Alabama.

Table 1. Material of instruction

Topic	Area
Front End Planning	Introduction
	Understanding Objectives
	Feasibility Phase
	Concept Phase
	Detailed Scope Phase
	Contractual Relationships
	SDE Roles and Functions
Project Execution	Introduction
	Project Execution
	Risk Management
	Contract Management Change
	Management Constructability
	Design Control
	Work Breakdown Structure
	Cost Management
	Schedule Management
	Calculating Variances
	Material Management
	Information Management
Project Completion	Introduction
	Project Start-up
	Project Close-out
	Team Building Concepts
	Leadership Applications
	Mentoring Responsibilities Career
	Development
	Role of the SDE in Review

Before attending each module, the engineers were assigned a set of pre-instruction readings. During the instruction of each module, the engineers were provided with a binder and a flash drive with the instructed material, handouts, and tools related to the module content. The modules were delivered to the engineer students in a traditional classroom style. The active participation of the students was not only encouraged but also demanded through discussions and question and answer sessions. Implementation workshops complemented the classes so that the engineers could consolidate the understanding and utilization of the principles and skills that they had learned in the classroom. In the workshops, the engineers were frequently requested to work in teams. According to the directions from the board, the workshop teams were intentionally assembled with engineers from distinct disciplines with the goal to increase their inter-disciplinary communication skills.

Self-assessment data collection

Once the training had been completed, a self-assessment tool was designed to determine the long-term effect that the training intervention had in the engineers. Specifically, the self-assessment tool was distributed among the SDE engineers several months after the intervention in order to capture the sustained impact of the training intervention on the knowledge (principles and skills) and the work practice of the engineers. The self-assessment tool consisted in 104 survey questions that summarized the key topics instructed during the training. The questions were grouped in sections of common knowledge within each instructed topic: 5 sections with 36 questions for front end planning; 12 sections with 50 questions for project execution; and 5 sections with 18 questions for project completion and team dynamics. Figure 1 illustrates a sample of the self-assessment questions.

Module:	Level of Understanding										Level of Implementation				
Project Execution	Pre-Instruction					Post-Instruction									
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Risk Management													x		
Understand the three phase process of risk management; identification, measurement or evaluation, and management or mitigation.		x							x						
Understand that measurement of risk must address frequency and severity.			x							x					
Understand the importance of the risk category guidelines found in the PEP.		x							x						
Understand uncertainty as it relates to risk.			x							x					
Understand risk control techniques, such as risk sharing, risk transfer, and contingency planning.		x								x					

Figure 1. Self-assessment questions

For each question, an engineer had to assess his/her level of expertise in the topic in a 1 to 5 scale (1 none or minimum; 2 some; 3 average; 4 much; 5 expert) both before and after the instruction. In addition, the engineer had to assess the level of implementation of the key concepts and skills contained in each section. The self-assessment tool was distributed to the participants by the board via email and with a note encouraging the engineers to complete the survey. A set of instructions to fill the survey questions accompanied the self-assessment tool, and the engineers were invited to contact these researchers in case of additional questions. A total of 38 survey responses, equivalent to a 76% response rate, were collected for the purpose of this study. Table 2 contains the distribution of survey respondents by engineering discipline.

Table 2. Distribution of survey respondents by engineering discipline

Discipline	Percentage of respondents
Electrical	18%
Instrumentation & Control	18%
Piping	8%
Process	16%
Mechanical	16%
Structural	24%

Impact on the cognition and work practice of the engineers in the construction work force

The intervention resulted in a positive impact on both the construction expertise and the work practice of the SDE engineers, as discussed in the rest of this section. First, the intervention significantly increased the cognition of the engineers in terms of basic construction principles and skills –See table 3. Thus, a sustained gain in principles and skills was actually determined for each of the modules of instruction −i.e. front end planning, project execution methods, and project completion and team dynamics. The sustained gain in the cognition of each instructed topic ranged between 1.53 and 1.69 in the 5 points scale. Indeed, these differences between the pre- and post-training means in cognition are statistically significant with a p_value<0.001. Moreover, the average construction expertise among the engineers after the intervention and across the three instructed topics was much uniform than before the intervention. See the pre- and post-standard deviation values in Table 3. Overall, the training intervention concentrated the construction understanding among the engineers around much higher levels of expertise, likely facilitating their alignment and communication.

Table 3. Summary of statistics

	Front End Planning		Project Execution		Project Completion	
Statistic	Pre-Instruction	Post-Instruction	Pre-Instruction	Post-Instruction	Pre-Instruction	Post-Instruction
Mean	2.28	3.95	2.20	3.89	2.43	3.96
Standard Deviation	0.52	0.28	0.33	0.23	0.46	0.28

Second, the survey tool unveiled an average (equivalent to 3 in the 5 points scale) implementation of the acquired principles and skills in the work practice of the engineers for the 22 sections of the survey. Even though this notable average of implementation, there was a marked unevenness in the work practice implementation within each section. Indeed, the level of implementation of key principles and skills in each section ranged from 1 (null) to 5 (maximum). This uneven utilization of the principles and skills instructed during the intervention was further investigated by means informal feedback, discussions, and email communications. It was unveiled that, while the engineers had very similar construction expertise as a result of the intervention, the chances to implement distinct concepts and skills highly varied with three main factors: constraints and opportunities for implementation, transfer climate, and peer support. Indeed, the work practice utilization of key principles and skills acquired during the intervention notably varied for each engineer. The importance of these three factors in the implementation of the acquired construction expertise is exemplified with distinct examples. For instance, constructability principles and skills (within the project execution methods module) require the opportunity to integrate construction expertise into the design documents. Thus, an advanced project with completed or near-completed design drawings and specifications did not facilitate the use of constructability principles and skills, while a project at a preliminary design stage facilitated the integration of construction knowledge into drawings and specifications. In addition, the work climate was observed to act as either a favorable or unfavorable factor in the transfer of the acquired knowledge to the work practice. Thus, in a climate with a low-pressure to deliver a project, an SDE engineer found a good opportunity to devote the time to transfer the acquired knowledge to his/her work. On the contrary, a high-pressure climate to deliver a project was regarded to play against the likely implementation of such knowledge, since the engineer had to focus all his/her efforts towards the advancement of the project with virtually no opportunity left to alter his/her practice. Finally, the peer support was regarded as fundamental for the transfer of the acquired knowledge into construction work. Even though each SDE engineer was responsible for all the construction work in his/her own discipline, such work had implications across disciplines, and hence the support of the engineers in other disciplines facilitated the implementation of new expertise and skills. Finally, it was also observed that construction engineering verbiage, concepts, and skills acquired during the intervention were utilized by the student engineers to communicate with engineers from other disciplines, and that the training intervention facilitated the alignment of the participating SDE engineers across disciplines and around common project targets.

Conclusions and recommendations

This study determined that there is a significant opportunity to transfer construction concepts and skills to the engineers in the construction workforce and into their work practice. The methodology of the study relied on a quasi-experiment that consisted in the instruction of front end planning, project execution methods, and project completion and team dynamics principles and skills to a convenient sample of engineers. The engineers, even though affiliated with an EPC firm, had no previous education in construction. Once the instruction was completed, a self-assessment tool was distributed among the engineers in order to capture the long-term impact of the training intervention on their knowledge (principles and skills) and work practice.

Based on the survey-collected data, a sustained gain in principles and skills was determined for each of the instructed topics. Indeed, for each topic, the difference between the pre- and post-training means of cognition was determined to be statistically significant. Also, the training intervention was observed to concentrate the construction understanding among the engineers around much higher levels of expertise. In terms of work practice, the survey tool unveiled an average implementation of new construction concepts and skills. However, while the engineers had very similar construction expertise as a result of the intervention, the chances to implement distinct concepts and skills individually varied among the engineers as a consequence of three main factors: constraints and opportunities for implementation, transfer climate, and peer support. Finally, it was also observed that construction engineering verbiage, concepts, and skills acquired during the intervention were utilized by the student engineers as a channel to communicate with engineers from other disciplines, and that the training intervention facilitated the alignment of the participating SDE engineers across disciplines and around common project targets.

This research has tackled the impact of an intensive training intervention in construction engineering to a sample of engineer students and from these engineers to their work practice. Future research efforts should further characterize the changes on the work behavior of the engineers as a result of similar interventions and evaluate the effect of such changes on the efficient delivery of capital facility projects.

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