Redeveloping a Senior-level Highway Design Course Considering Industry Feedback

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Abstract

The lack of practical real-world applications in a classroom setting has been identified as one factor inhibiting student interest in STEM fields. One approach to address this concern is the implementation of a course structure that largely mirrors professional practice. To this end, this study details the results of a project oriented toward developing a framework for the implementation of a highway design course that better prepares students entering the profession. To better align the course with industry needs, a questionnaire survey was distributed to public and private transportation agencies in order to assess the importance of various skills, resources, and classroom topics as they relate to the field of highway design. Results of the survey are discussed with emphases on differences between public and private transportation agencies of various sizes.

Introduction

Research suggests the lack of practical, real-world applications in a classroom setting is one of several factors that have contributed to students, especially women, shying away from STEM fields. Tseng et al. (2011) found real-world applications were especially effective towards encouraging broader participation in engineering. Relatedly, prospective employers are also well served by educational programs that serve to develop practice-ready employees. Consequently, numerous university programs have involved industry surveys to evaluate the readiness of recent graduates upon entering the engineering profession (Lianggrokapart et al. 2002; Crosthwaite et al. 2006; McDonald 2006; Nair et al. 2009). Developing degree programs and courses that match in-demand industrial skills with those acquired in a clasroom setting is critical for universities to meet the labor demands of a world transitioning from a “goods society” to a “knowledge society” (Witt et al. 2013).

However, gaps do exist between the industry and classroom settings (Howe et al. 2009; Donnell et al. 2011), which motivates the need for well designed surveys to better align the two. Such integration would also help to meet the 24 outcomes outlined by the American Society of Civil Engineers in *Civil Engineering Body of Knowledge for the 21st Century* (ASCE 2008), particularly those outcomes focused on professional issues. These outcomes, which focus on practice-oriented skills such as communication, leadership, teamwork, professional and ethical responsibilities are generally satisfied during the pre-licensure professional experience rather than as a part of the undergraduate experience.

Continuing on this point, engineering employers generally prefer students to have a combination of both strong technical and soft skills. For example, an industry survey by Hawkins and Chang (2016) found that companies often emphasize traits such as willingness to learn over more technical skills. Research also suggests these skills are particularly beneficial if acquired in a practical setting that mirrors industry (Vaz and Quinn 2015). Prior research has suggested this is an important element that is generally lacking from many engineering education programs (Anderson et al. 2009). Greater use of such active, hands-on learning could also improve the acceptance of women (Pereira et al. 2010) and minorities (Haak et al. 2011) in engineering.

Purpose

The objective of this study was to redevelop a senior-level highway design course for civil engineering students at a large Midwestern technical university. As a part of this effort, the research integrates input from transportation employers as a part of the course redevelopment. This addresses a broad area of interest with respect to educational outcomes and is particularly important as prior research has shown that materials and methods are generally not shared effectively between transportation engineering faculty based on an assessment of curricula from more than 200 universities (Peters et al. 2015; Hurwitz et al. 2015).

Survey Implementation

As a part of the course redevelopment, a primary objective was to identify the knowledge, skills, and abilities sought by employers when hiring entry-level engineers for highway design positions. To this end, a questionnaire survey was developed and distributed to public and private road agencies in order to assess the importance of the following items when hiring candidates for such positions:

- Various reference manuals, guidebooks, and software programs commonly used in highway design;
- Topics generally included in highway design curricula;
- Specific soft skills pertinent to engineering practice; and
- Experience in co-op or intern positions, completion of FE/PE exam, and completion of a master's degree.

For each of the previously listed topics, questions were structured on a five-point Likert scale to indicate the relative importance of each item from the perspective of the hiring entity. Respondents were also asked to self-identify their company as either a state DOT, county/municipality, local/regional private firms, or national/international private firm. The questionnaire was distributed using an online survey tool. The survey was ultimately distributed to two groups of employers in the highway design industry. The first group included engineering companies with a transportation sector or division that had hired students from the university during the past five years. Initially, a total of 893 contacts were identified from private sector companies and public agencies. This list was reduced by investigating whether the company had a transportation sector. The resulting list included 236 contacts. Many of these contacts were professionals involved in the human resources division of their respective company, so instructions were given to forward the emails to engineers in transportation design within their company. The second group that was contacted was comprised of the head design engineers for each state Department of Transportation (DOT) for the 50 states and District of Columbia.

A total of 82 agencies/companies replied to the employer survey (34% response rate) while 17 of the 51 state DOTs participated in the survey (33% response rate). Geographically, the survey respondents were primarily distributed throughout the Midwestern United States in the area surrounding the university at which the study was conducted. Although 19 responses did come from outside the Midwest, these were primarily received from state DOTs. Nearly all respondents identified themselves as engineers, with the exception of two who appeared to be human resources personnel. As a significant portion of the survey content focused on technical

skills, these responses were removed from the sample, leaving a total of 95 completed surveys. The distribution of respondents by transportation agency type is summarized in Table 1. Not all questions were completed by all respondents. For cases of missing data or where respondents were unsure, those particular entries were removed from the analysis, although the other questions for which valid responses were obtained were included in final analysis.

Table 1 – Summary of State-of-the-Practice Survey Respondents

Agency Type	Number of Responses	Percent of Total
State DOT	17	17.9
Local Agency	23	24.2
National Company	16	16.8
Local Company	31	32.6
Unknown	8	8.4
Total	95	100.0

Survey Results and Discussion

Tables 2-4 present the survey results for each of the questions described previously. Each table presents the average importance of each topic on a five-point scale (with 1 corresponding to unimportant and 5 very important). Responses are disaggregated by agency type, along with a total average across the entire sample.

Table 2 – Importance of Design Reference Texts and Software Programs

Reference Text	State DOT	Local Agency	National Company	Local Company	Avg.
A Geometric Design Policy of Streets and Highways (Green Book)	4.15	4.09	4.50	4.22	4.22
Roadside Design Guide	4.05	3.96	3.94	3.84	3.93
Manual on Uniform Traffic Control Devices (MUTCD)	3.40	4.17	3.71	4.03	3.87
State/Local Specifications	3.05	4.43	3.18	3.91	3.72
Highway Safety Manual (HSM)	3.35	3.57	3.35	3.72	3.53
Highway Capacity Manual (HCM)	3.05	3.00	2.81	3.23	3.05
Software Program	**State DOT**	**Local Agency**	**National Company**	**Local Company**	**Avg.**
AutoCAD Civil 3D	2.63	4.00	3.88	3.56	3.57
Microstation	3.79	1.95	4.29	3.63	3.41
ArcGIS	2.67	3.70	3.13	2.71	3.06
Synchro/SimTraffic	2.35	1.48	2.82	2.59	2.31
Vissim	2.16	1.40	2.53	2.15	2.04

Table 2 details the importance of several reference materials and software programs frequently used as a part of the highway design process. Unsurprisingly, the reference considered to most important for new hires was the American Association of State Highway and Transportation Officials (AASHTO) *A Geometric Design Policy of Highways and Streets*, also referred to as the "Green Book". The Green Book is generally adopted as the standard reference for highway design by state DOTs, outlining minimum criteria that are consistently used across the United States.

While the Green Book was viewed as the most important reference overall across the sample, local agencies (i.e., counties and municipalities) placed a greater emphasis on knowledge of state- or local-level design specifications, which typically provide additional guidance that is pertinent to local conditions. The *Manual on Uniform Traffic Control Devices* (*MUTCD*) and ArcGIS software were also emphasized more strongly by local agencies. This may be reflective of the broader skillset required of employees of such agencies, which are generally smaller and require employees to have more extensive breadth of knowledge as compared to state/national agencies that are generally larger and more specialized in terms of the scope of tasks provided to entry-level employees.

Beyond the Green Book, the other resource that was consistently viewed as important or very important by agencies was the AASHTO *Roadside Design Guide* (*RDG*). The Green Book and the RDG were the most frequently referenced resources in a review of highway design syllabi conducted as a part of this study. Other resources, including the *MUTCD*, the *Highway Safety Manual* (*HSM*), and the *Highway Capacity Manual* (*HCM*) were viewed as being less important. However, it is important to acknowledge these resources are generally covered more extensively in courses from complementary areas such as operations and traffic engineering. Interestingly, most of these additional references were viewed as being more important by local agencies, whether public or private. These data suggest further support that local agencies hire employees with an emphasis on breadth of knowledge. Both state DOTs and larger national companies, on the other hand, considered such familiarity to be less important. Presumably, the larger structure of these entities means they expect new employees to have a narrower skillset coming in, with much of the additional expertise being acquired while on the job. To this end, larger agencies frequently have in place training programs that allow new hires to rotate across various divisions, each of which has a narrower focus with more depth in specific areas such as design.

Continuing on this point, it is observed from Table 2 that the knowledge of reference guidelines and standards is generally of more importance to prospective employers than proficiency with technical software. This is an area that has generated considerable discussion within the civil engineering program at the university where this study was conducted. In senior-year exit interviews, students have consistently emphasized a need for more extensive software integration in the curriculum. However, with the exception of computer aided design (CAD) software, other programs were viewed as being less important. It should be noted that several of these software are of more of a supplementary nature to the design process. For example, Synchro/SimTraffic and Vissim are focused on level-of-service and capacity analysis. While important, these types of analyses are conducted to justify or evaluate design alternatives early on in the design process.

One discrepancy of note when comparing the importance of software across agencies is the striking difference in importance between the two major CAD packages, Civil 3D and

Microstation. State DOTs (3.79) and national companies (4.29), in particular, were more likely to prefer experience with Microstation. This is largely because projects conducted by, or for, state DOTs typically require use of this program, which includes several specialized highway design applications. In contrast, Civil 3D has a broader focus that is applicable across a wider range of disciplines beyond highway design. In fact, several professionals explicitly noted this difference in their survey comments.

Turning to the fundamental highway design course content, Table 3 illustrates the importance of 20 topics generally taught in design courses or utilized in the practice of highway design. The list of topics was assembled based upon a review of content from syllabi of university-level highway design courses, as well as from sections of state DOT design manuals.

Table 3 – Importance of Various Highway Design Topic Areas

Topic Area	State DOT	Local Agency	National Company	Local Company	Avg.
Design drawings	4.11	4.27	4.18	4.39	4.26
Drainage and runoff	3.84	4.23	3.94	4.35	4.13
Vertical curves	3.95	3.77	4.18	4.45	4.12
Horizontal curves	4.00	3.77	4.24	4.35	4.11
Intersections	3.79	4.00	3.71	4.07	3.92
Earthwork	3.74	3.82	3.76	4.03	3.87
Stopping sight distance	3.95	4.00	3.53	3.83	3.84
Design controls	3.89	3.68	3.63	3.77	3.75
Roadside	3.63	4.09	3.65	3.47	3.69
Pedestrians	3.22	3.32	3.59	4.10	3.62
Traffic control	3.00	4.05	3.24	3.50	3.48
Pavement systems	2.95	3.95	3.18	3.42	3.40
Temporary traffic control	3.00	3.77	3.18	3.50	3.40
Design flexibility	3.58	3.09	3.31	3.13	3.25
Capacity and level-of-service	3.37	3.05	3.00	3.27	3.18
Traffic safety	3.53	3.14	3.06	2.77	3.08
Economics	3.16	3.32	2.76	2.84	3.01
Environmental impacts	3.11	3.18	2.65	2.97	2.99
Access management	2.59	2.68	2.65	3.10	2.80
Intelligent transportation systems	2.89	2.57	2.56	2.50	2.62

Interestingly, the topic receiving the highest rating was design drawings, followed by drainage/runoff, horizontal curves, and vertical curves, each of which had average ratings ranging between important (4 on Likert scale) and very important (5 on Likert scale). The importance of design drawings to employers addresses a shortcoming of the curriculum at the university where this study was conducted. In fact, the curriculum of a freshman-level graphics course was modified the subsequent semester based on these survey results to include more extensive coverage of design drawings and CAD packages. The importance of design drawings to employers is also likely reflective of the context of this survey, which was focused on entry-

level hiring practices. Plan sheet creation is a common tasked included in the practical experience students gain as interns or co-ops.

The other topics that were highly rated by employers are generally part of the standard curriculum in highway design courses, such as the design of horizontal and vertical curves, intersections, and the roadside environment. The importance of these topics tended to be quite consistent across the four types of transportation employers. Design flexibility and traffic safety were both found to be significantly more important to state DOTs. These topics have increasingly been emphasized more nationally in recent years, particularly with the publication of national-level design guides and manuals on these specific topics. Local agencies and private companies generally tend to track changes at the DOT-level, so it is expected these topics will become increasingly important among these employers moving forward, as well.

In contrast, local road agencies tended to rate several additional topics as being more important, such as permanent and temporary traffic control, pavement design, and consideration of pedestrians in the design process. These findings are reflective of the nature of design of lower class roadways that would fall under the jurisdiction of counties and municipalities. It is interesting to note that the economic aspects of highway design tended to be of greater importance to public versus private organizations. Recently, there has been an increased focus on the manner in which public funds are utilized for transportation improvements.

It was somewhat surprising to see such strong emphasis on drainage and runoff design across all agencies. In a review of syllabi from 20 civil engineering programs, Turochy (2009) found only one class included drainage in its syllabus content. At the university where this study was conducted, this topic has historically been covered in a hydrology course, but not actively integrated into highway design. Several survey respondents also suggested that several software programs should be considered when teaching students about drainage within the context of highway design, such as the Federal Highway Administration's HY-8, the Army Corp of Engineers' HEC-RAS, and AutoCAD Storm Sewers.

It was also noteworthy that capacity and level-of-service ranked in the bottom third of topics among employers, especially considering Beyerlein (2010) found traffic flow characteristics and capacity studies to be rated very high among topics that should be taught in transportation courses as part of a 2009 survey. Also, Thomas (2006) found that among the public sector, highway capacity was the most desired skill from new hires. This difference may reflect that capacity/level of service knowledge are viewed as complementary, rather than necessary skills. Intelligent transportation systems (ITS) also received low scores across all agency types, though it is important to note ITS and related technologies are expected to become an increasingly important aspect of the design process with the continuing emergence of connected and autonomous vehicles. This finding may simply reflect this is not a widely desired skill among entry-level employees.

The last section of the survey focused on the importance of various soft skills and other qualifications of entry-level engineers to prospective employers. Table 4 provides a summary of feedback as to the importance of these areas. Supporting research by Hawkins and Chang (2016), employers identified the abilities to work as part of a team and to learn independently to be among the most important traits for new hires. Table 4 also shows that writing and presenting are surveyed

a full point lower than the top three skills on average. This is interesting as there have been extensive efforts to address limitations of engineering students in these areas in higher education. Soft skills have been emphasized by engineering employers for decades (Lipinsky and Wilson 1991). By now this is an established fact that communication skills are critical to engineers. It is remarkable then to observe in Table 4 that presenting and writing fall far behind teamwork for new hires. It is possible that although writing skills are important, employers assume this will be learned after employment begins. This is supported by Donnell et al. (2011) who observed a deficiency between writing skills students have versus what is expected.

Table 4 – Importance of "Soft" Skills and Other Qualifications

Skill/Qualification	State DOT	Local Agency	National Company	Local Company	Avg.
Teamwork	4.48	4.09	4.41	4.60	4.41
Lifelong and self-learning	4.01	4.20	4.49	4.56	4.34
Critical thinking	4.21	4.38	4.19	4.40	4.31
Ethical judgment	3.95	4.15	3.98	3.99	4.01
Innovation/creativity	3.69	3.81	3.68	3.71	3.73
Technical writing	3.55	3.46	3.83	3.46	3.55
Technical presentations	3.29	3.01	3.39	2.94	3.11
Management skills	3.16	3.19	2.94	2.83	3.00
Skill/Qualification	**State DOT**	**Local Agency**	**National Company**	**Local Company**	**Avg.**
Engineer-in-Training (EIT)	3.79	3.76	4.41	4.06	4.00
Co-op/intern experience	3.47	3.29	3.94	3.87	3.64
Master's degree	1.63	1.38	2.18	1.58	1.69

Local agencies, such as counties and municipalities, tended to diverge from the other employer types and found innovation, ethics, and creativity to be more important and teamwork to be less so. This is yet another finding that suggests smaller local agencies value the ability of engineers to work independently. These same employers also tended to put less emphasis into teamwork.

For desired qualifications, employers were particularly interested in students who had completed the Fundamentals of Engineering (FE) examination (and were thus Engineers-in-Training, or EITs). EIT certification was particularly important among private consultants, where professional licensure is often a requirement for various types of design work. All employer types also tended to value candidates who had completed co-op or intern positions, considering this moderately important for new hires. In relation to each other, private companies desired a higher level of skill than public agencies. Collectively, these findings highlight the importance of practical experience to hiring agencies, though it is interesting to note that master's degrees were the least important among the skills and qualifications that were evaluated.

Conclusions

Ultimately, the results of this study provide important insights as to how classroom practices may be tailored to meet the needs of prospective employers. The study also details differences

as to the relative importance of various skills from the perspectives of various types of transportation sector employers. Many of the findings affirm the foci of existing highway design courses, in addition to supporting previous research as to the importance of soft skills and other strengths that are most critical to entry-level professionals.

The subsequent stages of this research are detailing the revised curriculum and evaluating the effectiveness of this curriculum from the student perspective. Additional important insights will be gained by assessing student proficiencies across these areas during the course of their formal education. It would also be interesting to gain insights and perspectives from junior engineers who had recently graduated. Their perspective would be valuable since they are the least removed from the university setting and could offer important feedback as to the skills they personally found most valuable or what was the biggest gaps were between their engineering education and practice. This study also predominantly focused on employers from the Midwestern region of the United States. Additional input from a broader audience could compare how employer attitudes vary across other regions.

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