A Methodology to Define the Body of Knowledge in Civil Engineering

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Abstract

Policy 465 of ASCE proposes radical changes in the process and implementation of civil engineering education. A necessary step in that implementation is defining the Body of Knowledge (BOK) required in various topics within civil engineering, both at the time of graduation and at the time of licensure. This paper will explore, for a particular sub-discipline within civil engineering (structures), how the BOK should be developed and of what it might consist at both graduation and licensure levels.

Three groups have an obvious interest in defining the BOK: practitioners, faculty and students. A major issue in the process of defining the BOK is how the interests of these groups should be protected. There is a danger that small groups within the profession of civil engineering may end up defining the BOK without adequate representation of these groups. There is also a danger that the BOK may be defined in such broad terms as to be either meaningless (because the statements within the definition are "apple pie and motherhood") or overly subject to interpretation without adequate representation.

This paper presents a simple process to develop feedback from the interest groups defined above. This survey-based method has been tested on the BOK for the sub-discipline of structures. Three small and unscientifically selected groups were used to test the device: junior and senior undergraduates at the University of Iowa; faculty in the Civil and Environmental Engineering Department at the University of Iowa; and practitioners from the Iowa Section of ASCE. Two levels of knowledge were identified: that for graduating students and that for newly licensed engineers. The BOK was presented in a series of statements in the form "Graduating students must have knowledge of …" or "Newly licensed engineers must have knowledge of …" as appropriate. Responses were measured on a scale of 1 through 5, where 5 corresponds to strongly agree and 1 corresponds to strongly disagree. The results of the survey are presented and their implications are discussed.

Introduction

What should a civil engineer know, and when should she (or he) know it? This apparently innocent question has profound implications for the future of civil engineering as a profession in the United States. As such it deserves the most complete answer that can be given.

Part of the import of this question lies in what happens if we get the answer wrong. If too little knowledge is demanded of practicing civil engineers, then the result may be structures being designed in an unsafe manner, which would put the health and safety of the public at risk. That suggests that very high standards should be set. However, to go to extremes here would also have negative implications. If the bar is raised too high, then too few people will be attracted to civil engineering, and legislatures may strip the protection of licensure from the public.

How then can the question posed above be answered? Further, who has the right to answer it? Who are the stakeholders here? On one level, society is the stakeholder, but society per se does not have enough specialist knowledge to answer the primary question. We would suggest that three groups have a major stake in defining the body of knowledge for civil engineering. These groups are: Civil engineering students, civil engineering practitioners, and civil engineering faculty. However, we have no evidence that indicates these three groups are the correct three groups, and this matter (who gets to decide) should be an issue for discussion in the profession.

Having decided who the groups are with a say in the matter, the next step is to find out what their answer is to the question. There are a number of ways in which such answers could be gathered, but for this paper, we chose to use a simple, paper-based, survey.

The purpose of this paper is emphatically not to try and answer the question "what should a civil engineer know and when should she know it." Rather, the paper is focused on developing one methodology by which an answer to this question could be obtained. The import of the question is such that if it is not asked correctly, erroneous information will be obtained with potentially dire consequences. Thus, we do not claim that the results obtained from the surveys presented here are "the answers," but it is our hope that the results may indicate how "the answers" may be obtained.

Survey Questions

In designing the survey, there were two critical decisions to be made. First was how response should be measured. There are many tools that can be used for this. We chose to use a simple five-point scale where 5 represents "strongly agree" and 1 represents "strongly disagree." This is a standard measurement tool. One of its major benefits is that a score of 3 indicates neutrality and may thus also serve as a valid response when a responder is uncertain of the import of a topic.

The survey is constructed as a series of statements (51 in total). Those surveyed are asked to evaluate each statement twice. First they are asked to indicate how important it is for a civil engineer to have such knowledge upon graduation. They are then asked to indicate how important it is for a civil engineer to have such knowledge upon licensure.

The survey questions do not attempt to address all of civil engineering. They focus solely on the discipline of structural engineering within civil engineering. However, those given the survey were informed that the survey was not for a structural expert but rather for a practitioner of general civil engineering. This represents a weakness in the survey process as some respondents may have been confused about the scope and intent of the survey. A more complete survey would have covered all aspects of civil engineering, but the authors felt that developing such a comprehensive survey at this point was beyond the current scope of the work.

The authors developed the questions, and as such the survey represents their view of what might be important about structural engineering for a civil engineer to know. This too represents a weakness, and any study attempting to answer the "question" posed in the introduction would clearly need to be developed by a much broader groups of civil engineers.

The questions were divided into three general groups: Analysis, design, and ancillary knowledge. Questions were numbered for identification. Addendum A includes the survey form.

Survey Results

45 students in a professional seminar class took the survey. It was also sent to practicing civil engineers in Eastern Iowa who are "friends" of the Civil and Environmental Engineering program at the University of Iowa, and to the faculty in the department. In this group, there were 25 responses. We feel these numbers are sufficiently large to indicate whether this survey represents a useful tool, but clearly, the samples are nowhere near large enough to provide a definitive answer to the questions posed.

For statistical analysis response to each question is assigned a numerical score with 5 representing "strongly agree" and 1 representing "strongly disagree." For each question the median response value is computed and used to draw conclusions. The results are presented first for students, then for practitioners. Finally, their responses are compared.

For the most part, students either agreed or strongly agreed with the importance of all statements at both graduation and licensure. The exceptions are as follows. At graduation, students expressed no opinion for statements 13, 14, 17, and 18 (ANALYSIS: Virtual work, Matrix methods, Finite elements, Dynamic loads, Plates & grids, Shells & membranes), for statement 35 (DESIGN: Bridges) and for statements 43 and 44 (ANCILLARY: Marketing services, Business development). At the point of licensure, the only statement with which they did not agree or strongly agree was statement 13 (ANALYSIS: Virtual work) for which they again expressed no opinion. To some degree these responses are very surprising. We do not require our students to be familiar with finite elements (although many take the course) yet they "agreed" that such knowledge was important. Clearly, to be fully effective as a tool, some additional follow-up is needed above and beyond a simple survey.

Students clearly expect to be learning a lot between graduation and licensure. Additional analysis of their responses showed that in a number of areas they felt that importance of knowledge increases significantly between graduation and licensure. Statistical testing showed that student ranking of importance increased significantly for statements 2, 14, 17, 18, and 19 (analysis: Truss forces, Matrix methods, Plates & grids, Shells & membranes, Buckling), 25, 26, 27, 29, and 35 (design: Design codes, Beam design, Column design, Tension members, Bridges) and statements 37, 41, 42, 43, 44, 48, 49, 50, and 51 (ancillary: Soil mechanics, Time value of money, Project management, Marketing services, Business development, International marketplace, Sustainability, Cost estimation, Project financing) between graduation and licensure. These responses, especially the heavy expectation of an increase of knowledge in the ancillary areas, are most heartening. It seems most appropriate that students would learn a lot about business development (statement 44) in the workplace rather than in College.

The 25 respondents from faculty and practicing civil engineers gave somewhat different responses. Again, for the most part, this group of professionals agreed or strongly agreed with the importance of all statements at both graduation and licensure. The exceptions are as follows. At graduation, the professionals expressed no opinion for statements 16, 17, and 18 (analysis: Dynamic loads, Plates & grids, Shells & membranes), statements 31, 32, 33, 35, and 36 (design: Timber design, Masonry design, High rise buildings, Bridges, Shells & Membranes), and statements 43 and 44 (ANCILLARY: Marketing services, Business development). At the point of licensure, they either agreed or strongly agreed with most statements with the following exceptions. No opinion was expressed for statements 6, 7, 12, 13, and 16 (analysis: Frame deflections, Indeterminate deflections, Conjugate beam, Virtual work, Dynamic loads) and slight disagreement was expressed for statement 17 (analysis: Plates & grids). In the design category, no agreement was expressed for statement 35 (DESIGN: Bridges) and in the ancillary knowledge category, professional respondents agreed or strongly agreed with all statements.

These responses show a rather different pattern from the student responses. The professional group gave less importance at licensure than at graduation to statements 2, 5, 6, 7, 12, 13, 16, 17, 18, and 19 (analysis: Truss forces, Truss deflections, Frame deflections, Indeterminate deflections, Conjugate beam, Virtual work, Dynamic loads, Plates & grids, Shells & membranes, Buckling). In contrast, this group assigned more importance to statements 25 through 33 and 36 at licensure (DESIGN: Design codes, Beam design, Column design, Connections, Tension members, Slabs, Timber design, Masonry design, High rise buildings, Shells & Membranes) than at graduation. They also assigned greater importance to statements 39 through 44, 46, 48, 49, and 50 (ANCILLARY: Retaining walls, Pile foundations, Time value of money, Project management, Marketing services, Business development, Communications, International marketplace, Sustainability, Cost estimation) at licensure than at graduation. In summary, this seems to indicate they feel analysis is less important in practice than design and ancillary knowledge, a not untenable position.

The final stage of the analysis is to compare the responses of the two groups, at graduation and at licensure. At graduation, in the analysis category, the professional group assigns great importance to statements 2, 5, 13, 14, and 19 (ANALYSIS: Truss forces, Truss deflections, Virtual work, Matrix methods, Buckling). They assign less importance to statement 16 (ANALYSIS: Dynamic loads). In the design category, again at graduation, the professional group gave less importance to statements 31, 32, and 36 (DESIGN: Timber design, Masonry design, Shells & Membranes), while in the ancillary knowledge category they assigned less importance to statement 46 (ANCILLARY:

Communications) and more importance to statements 37 and 38 (ANCILLARY: Soil mechanics, Foundations). At licensure, the professional group assigned less importance than the student group to statements 2, 6, 7, 12, 16, 17, 18, and 19 (analysis: Truss forces, Frame deflections, Indeterminate deflections, Conjugate beam, Dynamic loads, Plates & grids, Shells & membranes, Buckling). In the design category, the professionals assigned greater importance than the students to statements 22, 23, 24, 28, 29, and 30 (DESIGN: Load paths, Gravity systems, Lateral systems, Connections, Tension members, Slabs). They assigned less importance to statement 35 (DESIGN: Bridges). Finally, in the ancillary knowledge category, the professional group assigned greater importance than the student group to statements 38, 39, and 40 (ANCILLARY: Foundations, Retaining walls, Pile foundations). They assigned less importance to statements 43 and 51 (ANCILLARY: Marketing services, Project financing).

Implications

The first item to note is that with one exception (for the professional group, at licensure, for item 17 ANALYSIS: Plates & grids) no statement was rated unimportant. Yet the range of knowledge expressed here goes far beyond the (recently re-accredited) civil engineering undergraduate program at Iowa and (we suspect) at most colleges in the US. Clearly, this needs to be evaluated further and may represent a phenomenon of “survey inflation” whereby survey respondents are reluctant to give negative responses for fear of disappointing the survey takers.

Beyond this somewhat worrying aspect, in general the responses are positive. Clearly, the different groups assigned differing degrees of import to different areas (professionals value design and ancillary knowledge more than students, for example) and that is appropriate. The professionals feel that the import of analysis diminishes as an engineer moves into practice and that too probably reflects reality.

The question remains whether this is an appropriate tool to determine the body of knowledge. It certainly provides interesting information, but there is a real problem with the way respondents seem to overrate the importance of topics. Perhaps the result of this study is that survey results must be used with great caution and interpreted even more cautiously.

Conclusions

A simple survey instrument has been used to attempt to determine what items constitute the body of knowledge for graduating and practicing engineers in a sub-discipline within civil engineering (structural engineering). The survey was taken by small groups of students and professionals.

The results of the surveys indicate significant differences in responses between the two groups, and significant differences in expectations for both groups between graduation and licensure. The only concern with the survey is that essentially all areas of the survey were deemed to be of importance, and as such it may be that survey instruments of this type have a tendency to “overestimate” the importance of topics and knowledge areas to the body of knowledge in civil engineering. Given this, the authors would suggest that such survey instruments be used with care in defining the body of knowledge. However, they also note that when so used, surveys can provide useful insights into what constitutes the body of knowledge in civil engineering.

Biographical Information

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Addendum A

The survey used in this paper is presented here.

	Knowledge Statement	Importance at Graduation					Importance at Licensure				
		Str. Agree	Agree	No idea	Disagree	Str. Dis.	Str. Agree	Agree	No idea	Disagree	Str. Dis.
	ANALYSIS										
Equilibrium	1. Know how to find forces on bodies in equilibrium										
Truss forces	2. Know how to find forces in trusses										

Frame forces	3. Know how to find forces in frames and machines										
Moment diagrams	4. Know how to find shear force and bending moments in beams										
Truss deflections	5. Know how to find deflections in trusses										
Frame deflections	6. Know how to find deflections in statically determinate frames										
Indeterminate deflections	7. Know how to find deflections in statically indeterminate structures										
Force method	8. Know how to use the force method to analyze indeterminate structures (trusses, beams, frames)										
Displacement method	9. Know how to use the displacement method to analyze indeterminate structures (trusses, beams, frames)										
Moment area	10. Know how to use the moment-area method to analyze indeterminate structures (trusses, beams, frames)										
Moment distribution	11. Know how to use the moment distribution method to analyze indeterminate structures (trusses, beams, frames)										
Conjugate beam	12. Know how to use the conjugate beam method to analyze indeterminate structures (trusses, beams, frames)										
Virtual work	13. Know how to use the virtual work method to analyze indeterminate structures (trusses, beams, frames)										
Matrix methods	14. Know how to use matrix methods to analyze indeterminate structures (trusses, beams, frames)										
Finite elements	15. Know how to use the finite element method to analyze more general structures										

Dynamic loads	16. Know methods of analysis for structures subjected to dynamic loads										
Plates & grids	17. Know methods of analysis for plates and grid structures										
Shells & membranes	18. Know methods of analysis for membranes, net structures, shells, and arches										
Buckling	19. Know methods of analysis for loaded columns (buckling)										
	DESIGN										
Loading	20. Have a basic understanding of loadings on structures (wind, snow, earthquake, etc.)										
Design criteria	21. Have an understanding of basic design criteria										
Load paths	22. Understand and be able to calculate load paths on structures										
Gravity systems	23. Understand gravity load resisting systems										
Lateral systems	24. Understand lateral load resisting systems										
Design codes	25. Have a basic knowledge of design codes										
Beam design	26. Be able to design beams (steel and concrete)										
Column design	27. Be able to design columns										
Connections	28. Be able to design connections										
Tension members	29. Be able to design tension members										
Slabs	30. Be able to design slabs										
Timber design	31. Have a basic knowledge of the design of timber structures										
Masonry design	32. Have a basic knowledge of the design of masonry structures										

High rise buildings	33. Have a basic knowledge of the design of structural systems for high rise buildings, industrial buildings, and residential buildings										
Specialty structures	34. Have a basic knowledge of the design of structural systems for specialty structures (e.g. parking garages, storage tanks)										
Bridges	35. Have a basic knowledge of the design of bridges										
Shells & Membranes	36. Have a basic knowledge of the design of membrane and net structures										
	ANCILLARY KNOWLEDGE										
Soil mechanics	37. Have a fundamental knowledge of basic soil behavior										
Foundations	38. Have a basic knowledge of the design of foundations										
Retaining walls	39. Have a basic knowledge of the design of retaining walls										
Pile foundations	40. Have a basic knowledge of the design of pile foundations										
Time value of money	41. Have a basic knowledge of the time value of money										
Project management	42. Have an understanding of project management										
Marketing services	43. Know how to market professional services										
Business development	44. Know the fundamentals of business development										
Ethics	45. Understand the role of ethics in structural design and in the construction process										
Communicat ions	46. Be able to communicate effectively in written, oral, and graphical form										
Quality control	47. Understand the importance of quality control in the design process and in the construction process										

International marketplace	48. Understand the differences of design and construction in the international marketplace										
Sustainabilit y	49. Understand the role of sustainability in the design process										
Cost estimation	50. Know how to estimate costs in construction										
Project financing	51. Have an understanding of the challenges and implications of project financing										