Int. J. Engng Ed. Vol. 22, No. 3, pp. 598–608, 2006
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Tackling the Research-to-Teaching Challenge in Engineering Design Education: Making the Invisible Visible*

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Translating research results into everyday teaching practice is notoriously difficult. In this paper, we focus on the growing body of research on design knowing and learning, and examine and make visible opportunities for getting this research to positively impact teaching in engineering design education. Core to the paper is the position that successful efforts to get research to impact teaching will involve an emphasis on educators and their teaching practice. In this paper, we situate our position in scholarly thinking concerning the research-to-teaching challenge, present results of an empirical analysis of current teaching practice in design education, and describe an on-going approach for supporting research into teaching that follows from the empirical results. We close with the observation that information on the decision making strategies of engineering design educators could be particularly helpful for getting research to affect teaching practice in engineering design education.

Keywords: engineering design; research impact.

INTRODUCTION

HOW CAN we ensure that the growing body of research on design knowing and learning has a substantial positive impact on how design is taught—and what students learn—in the years ahead? What are the critical considerations? In this paper, we focus on these questions and seek to make visible the invisible work of those 'change agents' who work the research-to-practice challenge. This group includes anyone interested in advancing engineering design education and confident that research on design cognition can play a role in that advancement (e.g. researchers, policy makers, funding agencies, and educators). Ideally, the work of such change agents is marked by efforts to reduce the distance between the abstract knowledge base and the concrete needs of educational settings and to transform what is known into ways to support educators in their teaching decisions. In the paper, we take the position that educators and their educational practice will be central to successful efforts to get research to inform teaching practice.

Questions about precisely how to tackle the research-to-teaching challenge in engineering design education are becoming increasingly relevant as the body of research on design knowing and learning grows. In recent years, design researchers have been studying a variety of aspects of design knowing and learning including questioning [1], movement across design representation formats [2], and problem formulation [3]. In our own work, we have investigated the overall design process [4], the nature of iteration [5], reflective practice in design [6], and the conceptions of design of practicing engineering professionals [7]. Additional syntheses of work on design knowing and learning add valuable perspectives on this literature [3, 8, 9].

In principle, this type of research should help design educators to anticipate learner needs and develop more effective learning experiences. Current theories of learning emphasize the importance of taking into account the prior knowledge and interpretive frameworks that learners' start with and the trajectories associated with learning in a particular domain [15]. The challenge of instruction is how to help learners build new connections and frameworks and thereby advance to more skilled levels of performance in a particular domain.

However, the paucity of good working examples of connecting research and teaching practice suggest we should be paying more attention to the details of getting research results to inform teaching practice. For example, in a recent citation analysis of papers describing design instruction in

* Accepted 16 December 2005.

engineering, there were few citations to papers describing research on **design learning and knowing**, illustrating a potential research-to-teaching gap [10]. At the same time, funding organizations such as the National Science Foundation are promoting this issue by requiring researchers to explicitly state their plans to ensure their research will have an impact. We are concerned that the research has yet to have a deep impact on instructional decision-making. Although such a research-to-teaching gap is not unique to engineering or to design education—indeed it might be expected—so concerted effort is needed to address it because insight into this issue could result in significant strides in the quality of design education.

So what should we be doing? How do we move ahead? While there are a number of specific activities we could investigate in this paper (e.g. running a workshop in which design educators read and discuss the original research or developing instructional modules based on the ideas embedded in the research [11]), here we focus on a more general strategy, that of focusing on the design educator and his/her instructional decisions. In the paper, we situate our position in scholarly thinking concerning the research-to-teaching challenge, present results of an empirical analysis of current teaching practice in design education, and describe an ongoing approach for supporting research into teaching that follows from the empirical results. We close with the observation that information on the decision making strategies of engineering design educators could be a crucial missing link for getting research on design cognition to impact teaching practice in engineering design education.

SCHOLARLY THINKING ABOUT THE RESEARCH-TO-TEACHING LINK

In this section, we consider some roots of the gap between education research and teaching practice based on our reading of the literature. This permits us to situate our specific research-to-teaching challenge (getting research on design knowing and learning to affect the practices of teaching engineering design) in the larger context of research-to-teaching in education. In the process we examine what makes connecting research to teaching practice both crucial and challenging, highlight promising trends in scholarly thinking about how to strengthen the research-to-teaching connection, and make visible the nature of this form of scholarship.

The gap between research and teaching, the literature makes clear, is nothing new. 'What the research says' is a negligible consideration in most routine instructional decisions, which are more often based on habit, tradition, experience, and expedience than empirical evidence. What is more, research is seldom the driver behind major education reforms enacted. For example, smaller class sizes in the elementary grades, which ushered in student-centered instruction in the twentieth century, were the result of pressure from teachers' unions and education professionals whose reform sentiments were persuasive—not especially because of 'research' predicting academic performance gains [12 citing 13]. Similarly, schools adopted more rigorous, foundational math and science curricula (as well as history and social-science curricula) in the 1960s and early 70s in response to American anxieties over Sputnik. The current performance-based assessment movement owes its foothold not only to concerns over equity and global competition, but to the total quality management and other continuous-improvement philosophies percolating in business in the 1980s.

Indeed, the tie between education research and education practice has generally been characterized as weak—both in the USA [12, 14–18] and in other post-industrial countries [19, 20]. As Reese [12, p. 15] argues (citing Cuban [13]), education policies are 'a mixture of ideological belief and political passion, occasionally informed by study and research'. The National Research Council's Committee on Learning Research and Educational Practice [15] has characterized research's influence as indirect, mediated by four arenas: educational materials, pre-service and in-service education of instructors, policy, and the public (including the media).

The charge against education research, of course, is not just that it plays an indirect, supporting role in decisions and policy: it is that so much of educational research is irrelevant. Historians who have looked at this topic [e.g. 12, 14, 16, 17] have observed that the separate institutional cultures of researchers, teachers, and policymakers have made for a mismatch (real and perceived) in goals, languages, and incentives among these communities. Like the field of engineering, education came to be seen as a science (rather than a profession to which students were apprenticed) only with the rise of universities as research institutions in the early twentieth century. What has counted as rigorous investigation has shifted ground since then.

For example, the first education researchers in American academe (ca. 1890–1920) shared a progressive-era belief in social improvement through scientific management and were eager to prove their scientific (rather than philosophic or historical analysis) credentials. Among their first and most ambitious projects was a large portfolio of school surveys, in which all manner of school conditions thought to be important for efficiency—buildings, programs, personnel practices, etc.—were inventoried and rated for school managers. Although several hundred surveys of major local school systems were produced under the guidance of university researchers, virtually nothing is known about how they actually affected classroom practice. This gap in the historical record, notes Reese, is a case in point that what has gone on behind the classroom door has traditionally been seen as either sufficiently scripted from the top-down, or as too much the province of the individual teacher to merit documenting. In either case, public examination of what has gone on in actual classrooms has not been deemed particularly important.

Today's accountability movement is clearly turning the notion of classroom practice as a personal and private activity on its head. Propelled by the accountability movement, and by new enabling technologies for sharing information, two forms of **use-inspired research** [21] in education are gaining predominance. Drawing on Stokes's [21] four quadrants of research, one form of use-inspired research resides in Pasteur's Quadrant (at the intersection of the quest for fundamental understanding and a consideration of use). Change agents who work this facet of the research-to-teaching challenge conduct research that attempts to answer practical questions of high concern to teachers and education policy-makers (e.g. what works, for whom, and under what conditions). Another form of use-inspired research located within Pasteur's Quadrant is unique to the professoriate: the scholarship of teaching and learning [e.g., 22–24]. The notion of a scholarship of teaching and learning builds on (but also goes beyond) the idea of a 'wisdom of practice' [25] that develops in response to specific problems of practice, requires detailed knowledge of students' thinking, and involves building humble theories about the utility of particular strategies in light of educational goals. Both forms of use-inspired research support more public justification of instructional decisions—a key part of accountability and educational transformation. Accountability is a lever for change only to the extent that knowledge about practices that produce good results are shared and aimed at a serving a collective purpose: building up the knowledge base for teaching.

So what does this information suggest about getting research on design cognition to inform the teaching of engineering design? First, these observations clearly underscore the challenge: design cognition will not automatically be incorporated into teaching practices—that much is clear. Second, the observations point to a potentially powerful strategy for design-learning researchers, a strategy of purposely framing and structuring research on design cognition as use-inspired. This means taking into account how the research will be used in support of instructional decision making and educators' reflective practice. It also means treating as a design problem itself the task of making research products useful for faculty and instructors during their instructional decision making. To do all these things effectively, we need to make a concerted, sustained effort as a research community to learn more about the faculty and instructors who are the target users of research on design knowing and learning; we need to learn more about their teaching practices, instructional decision making, and the contexts of their work.

CONTENT ANALYSIS: FOCUSING ON USERS

In this section, we present an analysis of the instructional choices that engineering design educators are making and the ways that they talk about these choices. These choices make visible promising directions for supporting design educators in using design cognition research to positively impact their teaching practice. The inspiration for this analysis follows from the ideas presented in the previous section, specifically the idea of educators as *users* of the research and a research-to-teaching strategy of finding ways to help educators *use* the information. The portrayal of design teaching presented in this section complements other efforts to understand teaching practice, such as general research on educators' conceptions of teaching [e.g. 26], educators' pedagogical content knowledge [e.g. 27], and educators' pedagogical design capacity [e.g. 28]; research on the concerns of engineering educators more specifically [29]; and other focused efforts to characterize pedagogical practice in engineering design education [9, 30–33]. This analysis complements the other work by drawing on the knowledge presented publicly in one Scholarship of Teaching venue: engineering education conferences and journals.

Methods

We investigated the content of 12 sources spanning the 1994–2001 timeframe (10 established engineering education journals and the proceedings of two major engineering education conferences). A total of 273 papers that had 'design' in the title were identified. The majority of the papers appeared in the proceedings of the two annual engineering education conferences, Frontiers in Education Conference (43.6%) and the American Society of Engineering Education Annual Conference (11.7%), and one journal, the *International Journal of Engineering Education (*16.8%). The remaining papers came from 9 journals, each providing less than 8% of the full data set. These journals ranged in audience (national and international) and discipline (discipline-specific and discipline-general). The remaining journals include: the *Journal of Engineering Education* (16 papers), *IEEE Transactions on Engineering Education* (13 papers), the *Australasian Journal of Engineering Education* (1 paper), the SEFI *European Journal of Engineering Education* (4 papers), the *Global Journal of Engineering Education* (1 paper), the *International Journal of Mechanical Engineering Education* (13 papers), the *Journal of Professional Issues in Engineering Education and Practice* (2 papers), the *International Journal of Electrical Engineering Education* (5 papers), and *Chemical Engineering Education* (21 papers). Because we focused on educators and educational practice, we did not include journals or conferences that are not primarily education oriented (e.g. design studies, international conference on engineering design, research on engineering design). The complete citation list is available in a technical report [34].

The content of the papers was analyzed using 10 categories in a 5-part coding scheme that addressed the following pedagogical issues (see Table 3): where design is taught, how design is taught, what students are expected to learn, how well it is working, and how authors talk about 'design.' Each category includes several possible codes. For example, the learning objective category (one aspect of what students are taught) encompasses 10 possible objectives including learning design, communication, and teamwork. The unit of analysis is at the paper level. If the topic of one of the codes is addressed in the paper then the code is assigned to that paper. The codes are not mutually exclusive. In each category all relevant codes are assigned to the paper. Codes generally evolved from a 'bottom-up' content analysis of the articles conducted by multiple coders.

The coding process was accomplished in three stages. In the first stage, four coders coded the same five papers over a 5-week period. Individual coding rationales were discussed to iteratively refine the coding scheme. The second stage consisted of two primary coders independently coding an additional set of 30 papers. Intercoder reliability was assessed as percent agreement. Intercoder agreement of 80% (i.e., both coders agree on 80% of the coded items) was set as a goal. All instances where coders assigned different codes were discussed and arbitrated to consensus. For the final stage, each of the two primary coders coded half of the remaining papers, and a subset of the papers was coded by both coders to monitor reliability. Average intercoder agreement for this last stage was 89%.

Results

The results of the coding for the 273 papers are presented in Table 1. In the remainder of this section we discuss some of the findings and elaborate on implications for research-to-teaching efforts.

1. *Where design is taught*. The results for the categories 'Discipline' and 'Student Level' illustrate where design is taught in the engineering curriculum. As shown in Table 1, fourteen engineering disciplines plus pre-engineering programs are represented in the papers included in the analysis. This suggests that authors from many disciplines are motivated to write about their design courses. The courses described occur at all four years of the undergraduate experience plus some at the pre-college and graduate levels. The majority of the papers come from two levels: senior (41.4%) and freshman (29.7%). This suggests that either design courses occur more frequently in the freshman and senior year, or that faculty who teach these courses are more likely to write about their courses. For examples of freshman level design activity, see the work of Sheppard and Jenison [32], Richkus *et al.* [35], and Rivera *et al.* [36]. For examples of senior level design activity, see Rover & Fisher [37], Fornaro *et al.* [38], and Titcomb & Carpenter [39].
2. *How design is taught.* The teaching method(s) chosen for a particular design course characterize the nature of the learning experience that faculty are constructing for their students. Another important element is the extent to which students engage in collaborative team design activities. The results for the categories 'Teaching Method' and 'Group Size' illustrate how design is taught in the papers included in the analysis. As shown in Table 1, the predominant modes for how design is taught involve teams of designers (66.7%) and full-scale design projects (44.7%). Several papers described innovative coursework that involved the redesign of local projects [e.g., 40], reverse engineering [e.g., 41, 42], or designing artifacts that were actually used in practice [e.g., 43]. Educators reported using a wide range of approaches to teaching design including computer-based lessons, problem-based learning activities, traditional lecture sessions, workshops or laboratory activities.
3. *What students are expected to learn*. The results for the categories 'Learning Objectives' and 'Motivation' illustrate the learning goals for design experiences and to some extent what motivated the authors to create or enhance a design experience. Fifty-eight of the papers did not explicitly include a description of the motivation of the work they describe. Of those authors that did describe a motivation, the predominant reason was an effort to improve teaching effectiveness (46.9%). Many educators were motivated by accreditation requirements (21.6%) and by input from industry (16.9%). Many learning objectives were included in the design courses described, with 'design' itself in the majority (76.6%). As would be expected, learning objectives for engineering fundamentals (43.6%), team experiences (41%) and communication skills (37%) were also included in many courses.
4. *How well is it working.* Evaluation can provide both formative and summative feedback allowing educators to make necessary adjustments. The results for the categories 'Judging Effectiveness' and 'Type of Data Collected' illustrate the extent to which authors were rigorous in their judgments about the effectiveness of the design course, project, or approach they were writing about. The evaluation of evidence reported in the papers ranged in level of thoroughness. For example, 35.2% of the papers included conclusions on student learning and

Table 1. Results of content analysis

1. Where design is taught	N = 273	
a. Discipline	**#**	**%**
Electrical Engineering	74	27.1%
Mechanical Engineering	72	26.4%
Computer Engineering	40	14.7%
Pre-Engineering	39	14.3%
Chemical Engineering	37	13.6%
Computer Science	23	8.4%
Civil/Environmental Engr	21	7.7%
Industrial Engineering	17	6.2%
Aeronautic Engineering	17	6.2%
Manufacturing Engineering	12	4.4%
Bio-Engineering	11	4.0%
Material Science Engineering	8	2.9%
Ocean Engineering	6	2.2%
Agricultural Engineering	5	1.8%
Nuclear Engineering	4	1.5%
b. Student Level	**#**	**%**
Senior	113	41.4%
Freshman	81	29.7%
Junior	55	20.2%
Sophomore	49	18.0%
Graduate	15	5.5%
Pre-college	12	4.4%
2. How design is taught		
A. Teaching method	**#**	**%**
Full scale design project	122	44.7%
Workshop/laboratory	63	23.1%
Computer-based lesson	49	18.0%
Traditional class structure	46	16.9%
Small scale project	41	15.0%
Problem based learning	31	11.4%
Industry related project	30	11.0%
Competitions	29	10.6%
Reverse engineering	16	5.9%
Creating something useful	9	3.3%
Redesign of local project	4	1.5%
B. Group size	**#**	**%**
Team (= 2)	182	66.7%
Individual	48	17.6%
3. What students expected to learn		
A. Motivation	**#**	**%**
Improving teaching effectiveness	128	46.9%
Accreditation requirements	59	21.6%
Industry input	46	16.9%
Recruitment and retention	44	16.1%
Colleague input	16	5.9%
B. Learning objective(s)	**#**	**%**
Design	209	76.6%
Fundamentals	119	43.6%
Teams	112	41.0%
Communication skills	101	37.0%
Real world experience	42	15.4%
Data analysis & experimentation	34	12.5%
Global/societal contextual understanding	18	6.6%
Professional/ethical resp	17	6.2%
Confidence	16	5.9%
Life-long learning	14	5.1%
4. How well is it working		
A. Judging effectiveness	**#**	**%**
General statement(s) w/o data	98	35.9%
Conclusions on learning & course; w/ data	96	35.2%
Conclusion on course; w/ data	42	15.4%
Conclusions on learning; w/ data	14	5.1%
No evaluation	13	4.8%
B. Type of data collected	**#**	**%**
Author's observation	207	75.8%
Projects	151	55.3%
Written reports	133	48.7%
Survey/questionnaire	83	30.4%
Tests/quizzes	34	12.5%
External audit	32	11.7%
Progress report	26	9.5%
Peer evaluation	20	7.3%
Student self-evaluation	18	6.6%
C. Lessons learned	**#**	**%**
Operational issues	97	35.5%
Hands-on activities	72	26.4%
Computers	59	21.6%
Time constraints	40	14.7%
Early design exposure	39	14.3%
Faculty workload	36	13.2%
Conceptual issues	34	12.5%
Expectation of students	33	12.1%
New approaches	32	11.7%
Interaction w/ author	30	11.0%
Learning method evaluation issues	23	8.4%
Evaluation of 'design'	11	4.0%
Patent rights	13	4.8%
Stages to developing a successful engineer	13	4.8%
5. How authors talk		
About design	**#**	**%**
General usage (no def.)	230	84.3%
Defined	22	8.1%
Coupled with another team	19	7.0%

course structure supported by data, while 35.9% of the papers included general conclusions unsupported by data, and 4.8% did not describe evaluation efforts in the paper. For examples of papers that included conclusions on student learning and course structure supported by data see Dent [44], Davis *et al.* [45], and Shooter & Buffinton [46]. The types of data reported covered a wide spectrum. Not surprisingly, authors were most likely to draw upon their own observations (75.8%) and assessments of student performance (e.g., the design project itself, written reports, etc.). Surveys and questionnaires were a common method to collect additional evaluation data (30% of the papers); less common, and potentially underutilized, were methods such as self-evaluations (6.6%) and peer evaluations (7.3%). A few of the papers included multiple methods (13.2%) such as a combination of observations, surveys, and written reports. An important part of the cycle of improving a course, project, or lesson is reflection on what worked well and what needs to be improved. The majority of the papers analyzed (74.6%) included a description of what we coded as 'Lessons Learned.' The challenges authors expressed most frequently focused on operational issues (35.5%), workload or time constraints (27.9%), and the difficulty of judging effectiveness (12.4%). Many benefits for student learning were also described. Specifically, 26.4% of the papers describe benefits for the students from hands-on experiences [e.g., 47, 48]. Authors also identified the use of computers (21.6%) and early design exposure (14.3%) as providing positive outcomes for students. To a lesser extent, authors identified lessons learned about their students such as realizing that there are stages to developing a successful engineer (4.8%) and understanding students' expectations (12.2%).

5. *How authors talk about design*. The authors of the 273 papers used the term 'design' in varying ways. Some authors used 'design' as a noun, such as a final product that is formulated to solve a problem. Others used 'design' as a verb, the process of formulating (designing) a solution. In 7% of the papers, the authors coupled 'design' with another descriptive word resulting in more specific terms such as 'circuit design' or 'mechanical design.' Only 22 (8%) of the authors chose to explicitly define what they mean when they use the term [e.g., 49-51]. The rest of the authors left the reader to infer a definition from the way the term is used in the paper.

Implications for research-to-teaching efforts

This content analysis showcases the existence of a community of design educators already engaged in a scholarship of teaching in which they make their teaching practices and their reflections on these practices public. As such, the content analysis helps research-to-teaching change agents identify those educators who may be particularly interested in and ready to bring research on design cognition to bear on their teaching. Further, the results of the content analysis can help these change agents focus their research-to-teaching efforts by helping them to a) identify entry points where educators can make use of research on design cognition and b) anticipate challenges the educators might have in mapping research to their circumstances.

The decisions, lessons, and challenges embedded in the content analysis suggest specific entry points for conversations with the educators about how research could inform their teaching practice. For example, the content analysis shows the educators as making a variety of decisions about which pedagogy to use to teach design, which population to emphasize when teaching design, and which specific learning objectives to emphasize. Research on design cognition can be used to make and justify these types of decisions. The research could also be used to address some of the ambiguities present in the papers, such as ambiguities about what specifically the students are expected to learn and ambiguities in how design is even defined.

A clear role of the research would be in helping to address the challenges that the educators reported such as challenges with assessment. For example, because of the prevalence of full-scale design projects, one research-to-teaching approach could be to use the research to develop tools for assessing student learning in the context of these projects. This might involve adapting student surveys and questionnaires, and introducing tools (such as rubrics) to assess students' design conceptions and performance (and change in these over time). In addition, this might involve developing good questions and prompts to elicit students' design conceptions and performance, demonstrating how to use the research to give students feedback, supporting both individual and group assessment, and ensuring educators can adapt assessment instruments for their own purposes.

The results of the content analysis can help change agents to anticipate instances where the educators may be able to successfully map the research of design cognition to their situation and instances where the mapping may be more challenging. For example, given the prevalence of education focused on freshman and senior level students, research with freshman and senior level students may be the easiest for the educators to use. On the other hand, the wide range of academic disciplines suggests that educators will likely be making use of design results from outside of their specific discipline, which may be difficult to translate to more disciplinary specific needs. Further, limited emphasis on defining design suggests that educators may find themselves reading research on design cognition that stems from a different vision of design than their own. These ideas can help change agents know how to choose and present research in order to leverage the easy mappings and manage those that may be more difficult.

DESIGNING A TOOL FOR THE USERS: THE DESIGN EXPERTISE CONTINUUM

The previous sections provide multiple implications to guide efforts on getting research on design cognition to impact the teaching of engineering design. The review of scholarly thinking highlighted a need to emphasize use-inspired research that can support evidence-based decisions, answer practical questions of high concern, and promote reflective practice. The content analysis expanded on aspects of a use-inspired approach by characterizing the specific needs of design educators. In this section we briefly touch on the question: What would a synthesis of the research on design knowing and learning look like if it aligned with these implications? What guidance could we provide those change agents seeking to help design educators in navigating the research-to-teaching challenge?

These are not trivial questions. These are questions we have been exploring in our effort to build a *design expertise continuum*. The goal of the continuum is to support users (educators and researchers) in visualizing growth toward acquiring design expertise and to use this information to address design teaching challenges. The continuum is part of a three-pronged effort to promote a

Table 2. The continuum—design choices, rationales, and alignment with other work

	Rationale	Alignment with previous implications
Identify appropriate course of action	• Ensure continuum helps user (the educator) to make use of the research results • This could include illuminate teaching and assessment targets, and progression or pathways towards these targets	*Goal of supporting evidence-based decisions* (articulate initial starting points, transitions or progression pathways, and learning targets) *Goal of answering practical questions of high concern* (address design educators challenges with assessment and with ways to overcome operational issues— e.g., rubrics can make assessment and course design more efficient)
Provide links to other research	• Promote synthesis • Support evidence-based decisions	*Goal of supporting evidence-based decisions* (articulate initial starting points, transitions or progression pathways, and learning targets) *Goal of promoting reflective practice* (provide mapping to facilitate pursuit of other research)
Use the language of design (what designers say and do)	• Make behaviors, thinking, attitudes visible in the actions of learners (concrete rather than abstract terms) • Recognizable and salient language that resonates with users • Provide insights into context of learning	*Goal of supporting evidence-based decisions* (building on existing knowledge base) *Goal of supporting evidence-based decisions* (prioritize conceptions and definitions of design) *Goal of promoting reflective practice* (connect to wisdom of practice and help make implicit knowledge explicit)
Organize in terms of dimensions and trajectories of design cognition and learning	• Include research data at various design experience levels (freshman, seniors, practitioners) • Allow comparison from one learning moment to another (e.g., novice-expert, more problematic-less problematic) • Dimensions represent pieces of knowledge or strategy used by learner to make sense of design situation	*Goal of supporting evidence-based decisions* (comparative studies of sufficient scale and depth) *Goal of answering practical questions of high concern* (prioritize bookend comparative studies of freshman, senior, practitioner levels of experience; prioritize design, teamwork, and communication dimensions)
Organization includes qualitative and quantitative learning trajectories	• Highlight potential learning trajectories for design expertise • Illustrate complexity of learning—starting points, progression (jumps, increments), and targets	*Goal of answering practical questions of high concern* (prioritize capturing anchor points and critical learning transitions across freshman, senior, practitioner levels of experience) *Goal of promoting reflective practice* (highlight complexity of learning)
Representational format to include text and images	• Data representations as successful entry point for engaging users • Raw data provides opportunities for users to interpret own meaning and to reflect on their own practice	*Goal of answering practical questions of high concern* (diversity of design pedagogy suggests prioritizing tools for adaptability over tools for a particular need) *Goal of promoting reflective practice* (representations as evocative of practice; users as interpreters—users may include the learner themselves)
Easy to append continuum	• Accommodate existing and new research • An ability to append the continuum might be a measure of usability • Promote reflective practice via opportunities to make private knowledge public	*Goal of answering practical questions of high concern* (prioritize a 'clearinghouse' approach that can centralize and build a knowledge base) *Goal of promoting reflective practice* (users as potential contributors)
Feasible	• Not capture whole space but provide rich details on a space of limited scope • Should serve as a jumping off point to promote future iterations	*Goal of promoting reflective practice* (provide entry points for others to contribute or evolve the design)

research-informed approach to engineering design education. The other two activities include a study of design expertise (to populate the continuum) and a demonstration of how the research can impact design teaching (using the continuum to inform enhancement and assessment of student learning).

To date, we have conducted a series of case studies in order to identify the range of available choices related to the kinds of information to provide and ways to effectively communicate this information. A summary of these choices, their associated rationales, and a description of their alignment with the implications from the previous sections is provided in Table 2. The body of information represented in this table may be imagined as a reflective practice space where we are iteratively working on the continuum and making our private decisions and rationales part of a public conversation. As an example, our first effort was a succinct matrix representation organizing previous design cognition research around a cohort of datasets and themes [6, 52, 53]. The matrix format has been extremely useful for facilitating productive conversations. At the same time, it is limited in its potential to suggest appropriate courses of action. A second effort, a matrix articulating learning objectives in relation to attributes of design competency [54] aligned well with the assessment needs of educators and accreditation agencies, yet was not firmly anchored in design cognition research.

More recent efforts have focused on identifying continuum dimensions (the knowledge and ways of thinking that would be represented) and continuum trajectories (the ways to characterize features of design learning). For example, we considered studies published in active design research communities (i.e., *Design Studies, Research in Engineering Design*) and focused on aspects of design knowing and learning likely to be evident in our own work (i.e., problem scoping, iteration, and metacognition). Using an elicitation strategy, we focused on the following dimensions: holistic systemic approach [55], problem framing [55], reversing the transformation function [56], personalized stopping rules [56], and breadth of problem scoping [57]. In this effort we grappled with the significant challenges of mapping abstract ideas to concrete knowledge and behaviors. As a result, we included the natural language of the researchers out of a desire to not prematurely over-simplify or potentially reduce opportunities to identify use-inspired implications. We also explored a variety of other perspectives on learning in order to broaden the space of potential design knowing and learning trajectories [58]. In our current phase version, we are conducting a thematic analysis of the conceptions of design held by the freshmen, seniors, and expert practitioners in our dataset. We plan to use the results of this analysis as an organizational framework for linking knowledge of design to design practice and performance [7].

Overall, our efforts in developing the continuum and assessing the alignment between our decisions and implications from the previous sections suggest our strategy of adopting a use-inspired philosophy has merit. We also uncovered emergent attributes of a research-to-teaching tool that are likely to be user-centered. As shown in Table 2, this byproduct is a formulation of the research-to-teaching problem that may help others interested in creating research-based tools for design educators or making their research more useful for the practice of teaching design. However, our strategy has yet to be fully assessed. A crucial next step would be to assess usability and utility of the continuum as a research-to-teaching practice tool.

Table 3 shows the coding scheme for content analysis.

DISCUSSION AND CONCLUSION

In this paper, we have focused on a specific research-to-teaching challenge: the challenge of getting research on design cognition to impact the teaching of engineering design. Core to the paper has been the position that successful efforts to get this research to impact teaching practice will involve an emphasis on the teaching practice and the educators themselves. In the preceding sections, we situated our position in scholarly thinking concerning the research-to-teaching challenge and presented results of a content analysis of current teaching practice. In the final section of the paper, we described one approach for supporting

Table 3. Coding scheme for content analysis

Pedagogical issue	Code	Description
Where design is taught	Discipline	The branch of engineering identified (e.g., ME, CivE, EE).
	Student level	The intended level of the student (e.g., freshmen, sophomore, junior, senior).
How design is taught	Learning method	The technique, process, or means by which students are taught (e.g., competition, full-scale design, reverse engineering).
	Group size	Were the students working alone, with peers, or both?
What students are expected to learn	Learning objectives	The learning goals discussed (e.g., communication skills, self-confidence, analysis and experimentation, global/societal impact, teamwork skills). These are loosely coupled to the ABET a–k criteria.
	Motivation	The authors reasons for applying the learning methods discussed or motivation for the problem being solved (e.g., accreditation requirements, input from colleague or industry, improve teaching effectiveness, recruitment and retention).
How well it is working	Degree of evaluation	The level of rigor behind statements about the effectiveness of the course (e.g., conclusions not based on data, conclusions based on data, no evaluation).
	Type of data collected	Type of information collected either as homework or from course evaluations (e.g., observations, projects and reports, peer evaluation, surveys, tests).
	Lessons learned	The conclusions that were drawn regarding the course (e.g., benefits of pedagogical approaches, challenges related to evaluation or course operation).
How authors talk about design	Use of ‘design’	How was this word used in the document: unspecified, coupled with a specific type of design (e.g., circuit design), or explicitly defined.

research-into-teaching that follows from the literature review and content analysis—an effort to develop a 'continuum' of design learning (a description of design knowing and learning at various levels and dimensions of expertise) to be used by engineering design educators.

We believe the main contribution of this paper lies in how it draws attention to two activities that are often invisible: the teaching practices of design educators and the activities of change agents interested in getting research to inform teaching practice. The sections of the paper illustrate the type of information that can be brought to bear on understanding these invisible practices, and suggest a range of additional information that could be used. For example, constructs such as pedagogical content analysis, other syntheses of design education practice, and disciplinary perspectives such as cognitive engineering, can help to shed light on the topics in the paper. Instructional decision making is one topic we are convinced needs more attention. While the idea of evidence-informed decisions is currently core to scholarly thinking on the research-to-practice challenge, the papers reviewed for the content analysis often alluded to decisions that were not supported by evidence or even explained. Thus, if we had to prioritize one open issue it would be the need to know more about teachers' decision making in the context of design education. How do instructional decisions get made? Who makes them? Under what conditions? Given what information?

This paper was intended for anyone interested in advancing engineering design education and confident that research on design cognition can play a role in that advancement. This group includes researchers wanting to ensure their research has an impact, policy makers looking for guidance on how to effectively leverage research, funding agencies setting priorities about what activities to fund, and educators who are looking for ideas on how to improve their teaching. Together, these people can function as change agents helping to advance the effectiveness of engineering design education.

Acknowledgments—This work was supported by National Science Foundation grants ROLE-0125547, RED-9358516, EEC-0211774, ESI-0227558, and REC-0238392 as well as grants from the GE Fund, the Ford Motor Company, and Boeing. We would like to acknowledge the accomplishments of our undergraduate researchers (Joshua Martin and Joshua Newman) for their professionalism in reading and coding over 250 papers, and Queenie Chung for her work in the citation analysis that supplements the analysis of design educators' instructional choices. Additionally, we would like to acknowledge Susan Mosborg, Roxane Neal, Angela Linse, Matthew Eliot and Eddie Rhone for the work and intellectual contributions to the projects described in this paper and the Laboratory for User Centered Engineering Education for their insights on the application of user-centered design ideas to engineering education.

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