Towards a Scholarship of Integration: Lessons from Four Cases

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Abstract

The purpose of this theory paper is to illustrate possible approaches to the scholarship of integration and explore features, challenges and outcomes of these approaches. Among the forms of scholarship – i.e., discovery, teaching and learning, integration, and application – the scholarship of integration emphasizes bringing together otherwise isolated knowledge by making generative connections within and across different perspectives and disciplines. These connections lead to new insights and language, and place specialized knowledge in a broader context, often revealing patterns that can be useful to specialists and non-specialists.

Some argue that this form of scholarship is becoming more central to academic work because it is better equipped for building interdisciplinary partnerships, developing frameworks that transcend disciplinary paradigms, and responding to complex issues at the individual and societal level. For engineering education, this type of scholarship can provide a mechanism for scholars to create new language, theorize and develop conceptual frameworks, and make cross-disciplinary translations for use in discovery, teaching, and practice. Yet, although valuable, the scholarship of integration is relatively underdeveloped and under-theorized.

In this paper, we unpack four scholarship of integration cases – focused on systems thinking, innovation, design teaching and learning, and reflection – with a goal of enhancing our collective understanding of this form of scholarship and ways to use it in engineering education. We employ a process of collaborative inquiry to reflect upon, analyze, and highlight common strategies and challenges in each of and across our cases. First, we provide individual accounts of our experiences, lessons learned, and scholarship of integration features, revealed through our collaborative process, that are embedded in our cases. We then highlight a common strategy and three common challenges that emerged through the collaborative inquiry process. We conclude with a question about the implications of this exploration for individual researchers, the community, and policy makers that warrant further conversation.
**Introduction**

The Boyer report,¹ *Scholarship Reconsidered*, articulated a new paradigm for scholarly activities that goes to the core of academic life: “the meaning of scholarship itself” (p. 1). Boyer expanded the concept of scholarship, traditionally viewed as the *scholarship of discovery*, to include three equally important areas: the *scholarship of integration*, the *scholarship of application*, and the *scholarship of teaching*. This view of scholarship has influenced policy conversations within and outside of academia – shaping reforms in the assessment of faculty work, tying research resources to teaching and learning, and influencing federal investment in undergraduate education and professional development for teaching.² Yet, despite the equal importance among these forms of scholarship, attempts to define or guide researchers to develop or evaluate scholarship of integration efforts have been limited.

In contrast to the emphasis of the scholarship of discovery on what is yet to be known and found, the scholarship of integration emphasizes the connectedness, meanings, and interpretations of scholarly byproducts. According to Boyer (p. 19), the scholarship of integration is “serious disciplined work that seeks to interpret, draw together, and bring new insight to bear on original research… fitting one’s own research—or the research of others—into larger intellectual patterns.”¹ These connections and interpretations can place the specialties in a larger context, open new research directions, strengthen research-to-practice (and practice-to-research) cycles, and create missing links within and beyond academia. They also help make sense of the increasing scope, scale, and complexity of the body of knowledge and its blurring disciplinary boundaries, and serve as the basis for projects with a qualitatively different form of inquiry.

While many cite the significant value of the scholarship of integration, it is relatively underdeveloped and under-theorized. Some argue that this form of scholarship has been slow to gain acceptance as an integral activity in the professoriate, compared to other forms³⁻⁵. Common reasons for this trend are the isolation of academic disciplines and a perception of interdisciplinary work as risky or too difficult, limiting the number of examples for others to build upon³. Further, existing avenues to make research/knowledge connections, such as systematic literature reviews and meta-analyses, although valuable for other purposes, seem to prematurely close the space in matters of interpretation and meaning-making. Systematic literature reviews, for instance, are meant to “critically appraise and summarize research to inform policy and practice”⁶ (p. 45). Similarly, meta-analysis “allows the evidence from different studies to be combined so that individual studies become data points in a large population of studies”⁷ (p. 290) for purposes of increasing power and reducing bias introduced by individual researchers. Beyond suggestions for “speaking to practice”⁸⁻⁹, little guidance is available for those who wish to engage in scholarship of integration efforts and/or evaluate them in terms of scholarly quality. Such guidance can be highly relevant in academic contexts such as tenure and promotion evaluations, manuscript reviews, and funding/grant allocation decisions.

In fields where disciplinary boundaries are often crossed or that live between such boundaries – such as engineering education – this type of scholarship could (and should) play a critical role. Much of engineering education involves bridging research fields (e.g., learning, thinking, design, assessment), and these connections draw new insights and research directions that are relevant to engineering contexts. The field strongly focuses on integration-related issues, such as research-to-
practice, enabling change, translation, and evidence-based practice implementations\textsuperscript{10}. In short, it seems like guides to engage in this type of scholarship are needed and there might be value in looking at the scholarship of integration as the engineering education community continues to build the research field. However, in engineering education we are more likely to see examples of scholarship of discovery (e.g., generating specific knowledge about the nature of engineering, learning and assessment, and educational systems), scholarship of application (e.g., using evidence-based practices applied to conventional problems of engineering education), and scholarship of teaching and learning (e.g., engaging in teaching as a scholarly activity and sharing the results with others). Available scholarship of integration examples are mostly in the contexts of health sciences\textsuperscript{3,4}, and business\textsuperscript{8,9}, with a small and hopefully growing number in engineering education.

In this light, the purpose of this paper is to unpack what the scholarship of integration (SOI) could look like and illustrate possible approaches to this type of scholarship. In this paper, we employ a collaborative inquiry approach\textsuperscript{11-12} to examine four SOI efforts – focused on systems thinking, innovation, design teaching and learning, and reflection – with a goal of enhancing our collective understanding of this form of scholarship and the ways to use it in engineering education:

- The systems thinking example highlights an approach for connecting research to practice, which was developed based on a synthesis of design thinking literature, vehicle design literature, and studies of engineering practice. The result of this synthesis was a set of design principles that was used in the development of courses and lessons that prepare students to use systems thinking techniques within the design process.
- The innovation example unpacks the process of developing a framework of design for high-impact innovation, which connected insights from the design, entrepreneurship, innovation, and systems schools of thought, and generated a model of design problem-solving that is tailored to address high-impact innovation challenges.
- The design example explores the process of developing the Informed Design Teaching and Learning Matrix, a cross-disciplinary synthesis of design cognition and education research that generated tools for shaping next generation studies into design learning progressions and guides for teaching and assessing design learning.
- The reflection example unpacks such a concept, by re-framing reflection as an intentional form of thinking, in which one revisits an experience with a meaning-making lens. Such a perspective of reflection helps align multiple bodies of literature around the topic.

In light of our four cases, we explore two questions that were central to our collaborative inquiry:

1. What common strategies did we use and what common challenges did we face? This question is motivated by the assumption that features common to our cases suggest what may be relevant to future work of this variety.
2. What implications do our cases suggest for: a) individual researchers interested in trying to do this type of work, b) researchers wondering if this type of work is relevant to their topic, and c) a community trying to decide if and how to value this type of work?

By sharing our individual experiences (cases) and collaboratively inquiring across them, we hope to illustrate common ideas that may be central to this type of work, and that should likely be part of an ongoing conversation about the nature and practice of SOI in engineering education research. Though we do not offer definitive answers, using our collective reflection upon and across our
experiences could support others as they consider if a current project or program might be an SOI effort, or as they find new directions in on-going projects that could benefit from this form of scholarship. Our examples and collaborative inquiry can also be potentially used to reflect upon the common strategy of keeping the user in mind throughout SOI efforts, the challenges of communicating (and assessing) quality and contribution, whether in a self-assessment mode or in peer-reviewed endeavors, as well as the relationship of SOI to other forms of scholarship. Still, other questions raised in this paper merit an ongoing conversation with the community, to understanding what it takes to envision, shape, pursue, publish, recognize, fund, and reward this type of work. Overall, through this continued discussion we hope to “learn with Boyer” about the scholarship of integration and its implications for the field of engineering education.

Methods

A Collaborative Inquiry Approach

This exploration began as discussions among colleagues who were engaging with SOI as a research approach for understanding different kinds of phenomena around ways of thinking: design, innovation, human-centered systems, and reflection. In particular, we aimed to examine the lived experiences of engineering education researchers who had engaged with an SOI approach, to ultimately co-construct a deeper understanding of our own experiences that would inform our future use of SOI and support others interested in applying this approach.

These discussions evolved into a more formal exploration of five SOI experiences using collaborative inquiry methods to connect reflection and sense-making about the practice of engaging with SOI. Collaborative inquiry has been used within the context of adult education, teacher development, and engineering education to help individuals “systematically examine [their] own practice with a view to purposefully [advance] our understanding...based on evidence and concrete experience” (p.6). This type of inquiry is typically comprised of cycles of reflection and action, whose form and timing are dependent on the purpose of the inquiry and the constraints of the group.

Typically, the first step in collaborative inquiry is to form the group. The selection of researchers and cases for this study was purposeful and opportunistic. We specifically wanted to highlight a range of research foci within engineering education as well as uses of SOI.

The cycles began with initial reflections on our personal experiences using SOI. For each case, described in detail in the subsequent section, we developed written accounts of the “backstory” behind our research experience, responding to questions such as “what were your personal goals and reasons for conducting this research?”, “what stood out as scholarship of integration?”, and “what were your lessons learned based on this experience?”. Then, we met as a group for the first time to share each of our stories and allow the other members to acquaint themselves with the different aspects of our work.
Table 1. Collaborative meaning making: Personal and professional features of SOI

<table>
<thead>
<tr>
<th>Metaphors and adjectives</th>
<th>What metaphors or adjectives would you use to describe your SOI experience?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivations</td>
<td>What kinds of personal and professional motivations influenced your SOI approach? What made this SOI effort “significant”?</td>
</tr>
<tr>
<td>Role of use-inspired</td>
<td>What was created or generated through your SOI effort? For what purpose? Who are your intended users? Was the aim for prescriptive or descriptive use? Generalizability or transferability?</td>
</tr>
<tr>
<td>Iterative, reflexive, integrative, translational approach</td>
<td>What did the work entail or require? How does this compare to systematic or integrative literature review techniques? Meta-analysis? What other techniques were used (beyond a literature review)? Why? What was the role of iteration, why? What was the role of reflexivity, why? In what ways might the ideas “boundary work,” “translational,” and “transdisciplinary” characterize your experience? What fields, disciplines, and perspectives were explored, and what was the experiencing of connecting across these ideas?</td>
</tr>
<tr>
<td>Quality</td>
<td>What would you describe as features of “good” SOI? What decisions impact quality? What is involved in making an SOI effort understandable to others? What parts of the work were made visible to others? Why? What is involved in making an SOI effort believable to others? What does a “coherent and explicit chain of reasoning” look like for SOI? What is involved in making an SOI effort apply to situations that were not the specific ones studied? What is involved in making an SOI effort significant? Did it involve contradicting something considered “true”? What is involved in making an SOI effort ethical (e.g., being mindful of how other work is represented, being mindful of inclusion/exclusion)?</td>
</tr>
<tr>
<td>Challenges and advice</td>
<td>What kinds of challenges did you experience? Did an SOI framing help or hinder you? What kinds of challenges did you experience regarding publishing or communicating your work? What help do you wish you had? What advice would you offer to others?</td>
</tr>
<tr>
<td>Outcomes</td>
<td>What was generated (e.g., new language, frameworks, knowledge) through this approach? In what ways were outcomes emergent or could not be predicted?</td>
</tr>
<tr>
<td>Boyer’s forms of scholarship</td>
<td>In what ways does SOI intersect with the other forms of scholarship? If we could talk with Boyer, what would you ask or want to talk about?</td>
</tr>
</tbody>
</table>

Our action items after each meeting were to find connections across the experiences by going back to our own experiences with the questions raised during the meeting. For example, in one cycle we explored individually what particular fields were involved within our studies and how we might characterize the “distance” between those fields. We approached our concrete experiences and our
work with SOI in a similar manner to how one might approach a grounded theory study. Specifically, we entered the analysis of our experiences with no preconceived notions or theories about where our systematic examination may take us. Each cycle of reflection and sense making brought us closer to a saturation point, where no new insights were emerging from our discussions. Throughout these cycles, we co-created documents to gather insights we were beginning to see across experiences or to capture what we termed “provocative questions” to shape future discussions. These became places of synergy that captured the space of our conversations in relation to features of our collective SOI experiences - from the personal to the professional (see Table 1). These shared work spaces enabled divergent thinking (broadening the space of issues discussed) and convergent thinking (bringing us back to a set of key ideas) as we continued our collaborative journey.

**Telling the Story**

After two months of cycles of individual reflection and collaborative meaning making, we transitioned to discussions about how to best share our experiences and findings to inform future use of SOI by the members of our five person community and others within engineering education. Drawing from examples of collaborative inquiry and multiple perspectives methodology from engineering education literature, we wanted to balance the intricacies of the individual stories with the overarching themes that arose by bringing together multiple perspectives from different areas of research.

In the next section, each author was asked to share the story of their experience with SOI in their own words, with the aim of providing readers an opportunity to “experience” a set of key ideas while also coming “into contact with...different languages, modes of communication, and forms of inquiry” (p.51). The authors were provided with guidance for the structure of these accounts, specifically (1) authors should aim to write approximately 1500 words or less about their case, (2) accounts should be written in first person, (3) accounts should include a brief history of the project and a basic description to provide readers with context, and (4) accounts should close with a brief discussion highlighting what the author found interesting about their implementation of SOI based on the cycles of reflection and sense making. Following the documentation of each case, the authors used these accounts as individual reflections and met again to collaboratively make sense of the accounts. The result of this last cycle of sense making is comprised within the discussion section.

**Cases**

Given the diversity of the research phenomena explored and the role of SOI in our respective studies, the following case narratives intend to provide the reader an opportunity to glimpse into the experiences of each of the authors. Each case begins with a brief history of why and how each of the authors engaged in their particular research study, presented using italicized text. The remaining paragraphs of each case describe key realizations that emerged through the cycles of collaborative reflection and sense making. These takeaways served as the foundation for our discussion and conclusion sections.
Four case narratives are described herein. Case 1 describes the systems thinking example in the context of Alexandra’s doctoral studies. Case 2 depicts Freddy’s exploration of innovation, also for his doctoral dissertation. Case 3a and Case 3b are interconnected, and present the viewpoints of Robin and David, the two co-authors of the design teaching and learning example. Finally, in Case 4, Jennifer tells the story of the reflection example.

**Case 1: Systems Thinking**

In the following story, Alexandra, a former doctoral student in aerospace engineering describes her experiences developing a scholarship of integration study at the intersection of aircraft design, cognitive engineering, and engineering design education for her dissertation. The story is followed by her description of the key SOI features that were revealed through the collaborative inquiry process.

Pan into a large lab space filled with students at desks and a few 3 to 5 foot helicopters on tables scattered throughout. Noises are a blend of key types, whispers, and coffee brewing. Camera descends on a single student at her desk. She is wearing large black headphones and is slowly (and gently, if that is possible) hitting her head on the desk in front of her. After a few rounds she just lays her head on the table.

As an aerospace engineering doctoral student who was passionate about improving aerospace engineering education, I was at a loss of how to conduct research that would satisfy the research quality criteria of my discipline, while also having an impact on the educational practices of my discipline. My solution was to focus on a topic that lived at the cross-section of aircraft design, cognitive engineering, and engineering design education, specifically, how to improve students’ preparation to integrate systems thinking into the design of complex systems like aircraft. One of the critical tasks when utilizing a systems thinking approach is to consider who the stakeholders are that impact and are impacted by the system. From my observations of student design reviews and my coursework in cognitive engineering, I had come to realize that more explicit integration of stakeholder considerations could improve the effectiveness of complex systems designs developed by students and those created in industry.

When I first started down this path, I had envisioned employing a scholarship of application approach to this dissertation, by discovering something within the literature of engineering design education, cognitive engineering and/or aircraft design that I could modify and apply to a classroom setting. Yet, I quickly learned that no one discipline had the answer on how to integrate these systems thinking techniques effectively into the aircraft design process.

As the principal researcher on this project, which was funded by a National Science Foundation Graduate Research Fellowship, there were moments where I was mentally torn in different directions trying to understand how to bring these disparate perspectives together to support student learning. I regularly felt like an emissary, transporting learning theories from engineering design education to aircraft design, translating fundamental principles from cognitive engineering into language and tools that senior level students could implement, and decoding the concepts and processes used by aircraft designers for members of both the cognitive engineering and engineering design education communities. To support my work, I assembled a multidisciplinary committee to provide me with feedback from their different disciplinary communities. Yet, at the end of the day, even with their help, I was still the only one trying to sit at the center of these communities and resolve the differences I found in my work.

At this stage, it was clear that I was going to have to rethink my approach. I realized I needed to answer the following questions:

1) What were the best practices as discussed in the aircraft design and cognitive engineering literature for considering stakeholder impacts during the design process? What challenges did the literature discuss?

2) To what extent and how did practicing engineers and designers integrate stakeholder considerations into an aircraft design?
3) How were systems thinking principles already incorporated into engineering design education and aerospace engineering education?

4) Were students already systems thinkers when they started their senior design course? If not, to what extent did they already consider stakeholders and other systems components within the design of an aircraft, as one example?

To understand the best practices (and challenges) of designers (both engineers and non-engineers) for incorporating stakeholder considerations into the design of an aircraft, I conducted a case study in industry using human factors and interdisciplinary collaboration theories to describe the findings. I also examined engineering design literature and compared their perspectives on systems thinking and the integration of stakeholder considerations with the results of an exploration of current aerospace design textbooks and syllabi. Finally, I developed a survey using engineering design education research to learn from the participants in my study about their prior knowledge of and preconceptions about complex systems design and the value of considering stakeholders.

The initial round of integration of these topics was the definition of design criteria for an a set of two lab sessions to be delivered during senior design and subsequently, the design of those two sessions. Iterations of the design criteria and the lab sessions occurred behind the scenes with committee members. The implementation and evaluation of the lab sessions was utilized as a large scale iteration, which allowed me to uncover additional environmental considerations that should be accounted for in the design of future lessons, courses, etc.¹⁹

So, what was my motivation? It wasn’t until after completing the study, and many conversations with committee members about how to document and present my results, that I began to see my work as scholarship of integration. The scholarship of integration approach was ultimately used to make sense of two scholarship of discovery studies (i.e., a case study of aerospace design practice and a study of students’ preconceptions) and a review of literature and common practices within three different fields (i.e., cognitive engineering, engineering design education, and aircraft design). In terms of approach, two artifacts emerged from this meaning making: (1) a framework for instructors to use in designing lessons and courses in this area and (2) a model of how to translate industry-based research and classroom-based findings into education practice and a set of important environmental considerations for that translation.

From our collaborative inquiry discussions, I began to see how my work as use-inspired, with the aim of reducing the “distance” between the different fields for particular use cases. For researchers in cognitive engineering and aerospace engineering, I wanted to share with them conditions which support the integration of stakeholder considerations in the complex systems design industry. For aerospace design instructors, I wanted to enable them with a theoretically-grounded, empirically-informed framework for supporting their students’ development of systems thinking skills and specific learning environment considerations to keep in mind when designing lessons and projects. Understanding that I maintained certain conditions of use for my work helped me integrate the ideas from the different studies and disciplines in a manner that supported those conditions.

Within our discussions about how we each approached our work, we noted how we all traversed different disciplinary boundaries and tried to unpack whether our processes were inclusive, exclusive, or a bit of both. In my work, I believe it was my conditions of use that drove my decisions on what to exclude and what to include. For example, I was exclusive in the sense that ultimately I planned to focus on the integration of stakeholder considerations as one aspect of systems thinking within the context of complex systems design, as opposed to more general product design. Yet, I was inclusive in terms of trying to respect the disciplines I was considering and being mindful of their perspectives and needs, as they related to this topic.
Finally, as other authors note, I spent significant time exploring the challenges of deciding what part of my work should/is visible to my audience. One advantage to the use of scholarship of integration within a dissertation context is that I was required to explain my methodological choices throughout the document. In addition, I was not restricted to a particular page count, and even though my degree was in aerospace engineering, my committee was multidisciplinary, thus I was required to write with all of those perspectives in mind. During this writing, I benefitted greatly from using a non-standard chapter format, (i.e., I did not have a formal literature review or methods section). This format allowed me to frame my process and discuss how all the pieces were integrated by building on the overall findings with each new chapter.

**Case 2: Innovation**

In the following case, Freddy, a former doctoral student in civil engineering describes his experiences studying high-impact innovations and innovative thinking through an SOI. Similar to the systems thinking case, the story is followed by the description of the key SOI features that he came to understand about his story through the collaborative inquiry process. This story adds richness to the insights in the first case (e.g., types of motivations, use-inspired, iterative, integrative and translational nature, and living between Boyer’s forms of scholarship). It also brings in the role of challenging paradigms to offer new integrative ones, adds the notion that this type of study is seemingly “never done”, and that outcomes can serve as platforms for research and practice.

Big innovations, those of the size and significance of X-rays, transistors, lasers, and GPS, take time – often multiple decades – before benefits trickle down to society. Yet, in an era of increasingly complex and rapidly evolving “grand challenges,” and breakthroughs in promising areas such as the microbiome and the internet of things, might there be a way to make high-impact innovation slightly more systematic?

I have always had an interest in this question and decided to tackle it during the course of my doctoral studies, which were advised by Joe Sinfield. Innovation, however, is a broad topic, one that could perhaps be said to have no home as it lives across fields such as management, technology studies, design, engineering, economics, engineering education, and psychology.

Those who study innovation tend to focus either on characterizing innovation or on characterizing innovators, and at the outset of my study I felt a strong tension while trying to decide which one – innovations or innovators – to focus on. Although I could not understand why, I felt strongly inclined to study both, and thus my dissertation focused on two areas: 1) characterizing high-impact innovations, and 2) mapping the space of patterns of thought and action to pursue them. It turns out, the link between these two areas is more important than I thought because worldviews on innovation silently influence the innovator’s approach.

In my study, I employed three approaches to characterize high-impact innovations and the patterns of thought and action that facilitate their systematic pursuit: thematic analysis of historical case studies, a generative literature review/meta-synthesis of the innovation and innovator literature across domains, and verbal protocol analysis of performance tasks. The outputs of each of these approaches were connected into the two primary byproducts of the study – a new model of innovation, called enabling innovation, and a framework to design for high-impact innovation.

Historically, innovations have been a subject of broad study, with many efforts implicitly attempting to answer variations of the question: “What makes a solution highly innovative?” Terms such as radical, disruptive, and breakthrough innovation belong to rich, distinct schools of thought, and are typically used to described innovations considered to be of high impact. However, review and re-interpretation of these schools of thought, combined with the analysis of historical innovations, revealed that their locus is the local object of innovation and the many forms of comparison that can be made between such an object and predecessors or alternative solutions.
Effectively, some schools of thought emphasize an innovation’s novelty by tacitly focusing on the question: “How is this solution different from those currently employed in practice?”

Although a subject of much debate, I define innovation as the introduction of a novel or different idea into use or practice that generates a positive impact on society. In this view, a solution is not considered “innovative” until it is introduced into practice and impact is (or begins to be) realized. Over time, and after iterative analyses of literature and historical case studies, this led me to realize that the construct of impact had potential to be a new perspective from which to view innovation; a perspective that focuses on the question: “What type of impact can this new or different solution generate?”; thus changing the locus of innovation. Additional reviews and case studies revealed that some innovation schools of thought, such as general purpose technologies and market-creating innovation, focused on impact from an economics perspective. I realized that innovations can lead to different impact patterns, and attempted to generate a structured definition of impact. This in turn led to more case analyses, reviews of impact literature across fields, and discussions with committee members, eventually settling on a view of impact that consists of four dimensions – reach, significance, paradigm change, and (more recently) longevity – which can be used to characterize innovations. Such a view of impact helped me differentiate between two types of innovation – enabling and progressive – which vary in the aforementioned impact dimensions and unfold in characteristic ways over time.21–22

The impact-based view of innovation is strongly linked to the second workstream: the study of patterns of thought and action that can be employed by those facing complex innovation challenges. Here, efforts began with a “meta-synthesis” of innovative behavior across the fields of management, entrepreneurship, systems, psychology, design, and learning. I focused on identifying patterns of thought and action (which for simplicity I called “behaviors”), purposely leaving out attitudinal traits (e.g., risk seeker/averse, curious, grit/perseverance). As I learned more about what would eventually become the enabling innovation model, I realized that most frameworks of behaviors related to innovation seemed somewhat disconnected from work on innovation typologies. (Similarly, as I learned more about innovation behaviors, I discovered more patterns and connections in the enabling model, i.e., the innovation model and design framework “co-evolved”.)

The tension of wanting to study both innovations and innovators helped me realize that a framework to design for high-impact innovations should likely consist of behaviors that are linked to the characteristics of an innovation model. If the desired outcome of a design process is enabling innovation, then design patterns and behaviors should be linked to the characteristics of such a model, and strive for broad reach, comprehensive significance, paradigm change, and longevity.

With this new worldview, I iterated – multiple times – on versions of the framework, integrating evidence from the actions of stakeholders involved in historical cases, analyzing the responses of participants in the performance tasks, and reviewing additional literature. Because I was trying to identify behaviors linked to an innovation model that was under development, I decided to view my framework as generative (a starting point) rather than definitive. Also, because the elements of the enabling model were co-evolving with the framework, behavior inclusion criteria based on counts and frequencies of themes did not seem to make much sense. I thus decided to include design behaviors in the framework if they captured a specific nuance or were linked to a pattern in the enabling innovation model. After multiple iterations, the end result is a framework of behaviors to design for high-impact innovation,20 which characterizes a qualitatively different form of design – one that links design approaches with the characteristics of innovation typologies, and that, along with the enabling innovation model, is a platform for future research directions.

In this story, the explicit shift in the locus of innovation, from novelty to impact, illustrates how in the scholarship of integration changes in worldviews can integrate bodies of literature and open up new research directions. Creating new meanings for the word innovation – around impact-making – opened up new paths for all of Boyer’s forms of scholarship (discovery, teaching and learning, application). The enabling innovation model, for example, lives at the intersection of integration and discovery, as putting forward a model could be considered a discovery activity, but such a model stems from the re-interpretation of a field through new connections, which is an integration activity. Through our collaborative inquiry discussions, I reflected upon the notion that
the scholarship of integration calls for exploration of new worldviews that can generate new directions as an outcome. These changes in worldview could be the result of challenging known central assumptions in domains, or of articulating and/or structuring hidden assumptions that if viewed differently would unearth alternate paths to all forms of scholarship.

The aforementioned changes in worldview could be considered integration claims, and in our collaborative inquiry we discussed that, in assessing the quality of approaches and outcomes in this type of study, integration claims should be separated from other types of claims. In this story, for example, rethinking the locus of innovation – from novelty to impact – is an integration claim, while separating innovations as enabling or progressive is a discovery claim, and both claims should likely have a different basis of evaluation. In our collaborative inquiry, we considered research quality frameworks (e.g., NRC, UBASE, Q3) as starting points for integration claims, and found common ground in our efforts to unpack the work and make choices and approaches as visible as possible, which our discussions revealed as having created challenges in setting boundaries for scholarly byproducts.

Our collaborative also helped us see how the scholarship of integration can be integrative and translational, leading to reduced distances between fields. For example, in the development of a framework to design for high-impact innovation, my research helped create a connection between two broad schools of thought design approaches and innovation typologies. In creating this connection, I had to cross disciplinary boundaries and span fields such as design, entrepreneurship, innovation studies, management science, organizational behavior, psychology, learning, and technology studies. In ensuring the quality of the study, to be ethical and believable, I had to embrace all types links (complementarities and differences) to existing bodies of work, such as dominant design theories, modularity and interdependence theories, “disruptive innovation,” “informed design,” the “innovator’s DNA,” and the “lean startup.” In addition, my story in particular connected insights from literature to other approaches, and by reflecting on this multifaceted nature, I also realized that the scholarship of integration can entail methodological approaches beyond those categorically related to literature reviews.

Our discussions also helped me realize that many insights would likely have not been realized without the tension (and motivation) of studying innovations and innovators, and thus this tension helped me place communities into larger patterns to reveal emergent links between them. Such connections thus could be considered to stem from taking a broader systems-level view of the challenge of innovating, and using such a view to pinpoint a seemingly missing link between the design approaches (the things that innovators do) and innovation typology (the types of outcomes that they create) communities, leading to the identification of potentially synergistic knowledge between these communities.

In addition, this story could be considered to have a use-inspired nature – i.e., a dual quest for fundamental understanding (of innovation) and practical considerations (for societal “grand challenges”). This dual quest influenced how the work evolved and how it was framed as scholarly, striving for a balance between descriptive and prescriptive insights, and iteratively finding and testing patterns for use in scholarship and practice. Our discussions helped me realize that, in my story, the desire to speak to research and practice yielded artifacts as outcomes, which serve multiple purposes: a) as one of the places where integration happens, b) as one way of speaking to
both scholars and practitioners, and c) as starting/generative points for future research and practice. Both model and framework use conceptual graphics as artifacts to scaffold thinking and doing related to innovation. For instance, the enabling innovation model is synthesized into a key figure that characterizes the development of innovation impact, and the framework to design for high-impact innovation is synthesized in a figure that identifies a set of design “patterns” and “behaviors” that are linked to the characteristics of high impact innovations. Such behaviors aim to speak to researchers and practitioners, but are not claimed as definitive and are rather proposed as generative.

**Case 3a: Design Teaching and Learning**

In the story that follows, David, an associate professor of education describes his experiences in the early stages of an SOI effort focused on design teaching and learning. Within the story, he describes the genesis and evolution of the concept of “informed design” as well as key SOI features he shared as part of the collaborative inquiry process. This story adds richness to the aforementioned two cases by further illustrating how SOI studies are seemingly never done, showing iterations with a use-inspired point of view, and opening up the topic of publication challenges. The story is followed by the SOI experiences of his co-author, Robin, in Case 3b.

My story focuses on the formulation of ideas and early phases of writing a paper that was eventually published in the *Journal of Engineering Education* with the title, “The Informed Design Teaching and Learning Matrix.” An account of the later phases of writing this self-described “scholarship of integration” effort is provided by the paper’s second author, Robin Adams, immediately following this case. The final 60-page document sought to articulate the construct of “informed design” that would be helpful when engineering design tasks got used in K-16 classroom settings, a framework for articulating the design Pedagogical Content Knowledge (dPCK) that effective design teachers need in order to build design capabilities in students, and tools for teachers to help them navigate the complex instructional demands associated with using design tasks, many of whom had little training in engineering design themselves.

The idea of “informed design” came to me in 1998 when developing an NSF-funded, design-based science curriculum at Georgia Tech. I had done similar materials development at TERC in the 1990s with NSF backing. While working on both projects, NSF program officers were loudly and clearly saying that engineering design tasks, when placed in K-12 settings, should not only be highly engaging to students, and increase their awareness and interest in STEM careers, but most importantly, students needed to learn and apply science and math ideas while making the raft of design decisions that accompany any reasonably complex hands-on design challenge. Many in the field acknowledged that STEM ideas were relevant and could be applied when solving design challenges. They needed, however, to seem accessible and useful to students in this work, otherwise they would be relegated to the junkheap of students’ inert knowledge. It came to me that a succinct way to describe this long sought-for aim was to help students become knowledgeable novices, informed designers, who had some handle, if not command, of both relevant concepts and design-related practices.

My work while at Georgia Tech shifted from developing design-based middle-school science curriculum, to creating video-based support materials for teachers who wanted to use of design activities with their students. As PI on the project, I worked with others in videotaping and editing instances of average to mastery teaching with a wide range of published design activities. While shooting hundreds of hours of classroom video, I noticed how some of the less experienced science and technology education teachers were not intervening in ways I had seen MIT mechanical engineering design professors do with their students while doing engineering education research in 1989-92 and completing my MS there. Teachers were not noticing naive designer behaviors and habits of mind when they showed up in their students’ actions and comments.
I wanted to help teachers, most who were neither engineering designers nor design teachers, build the “professional vision”25 that would enable them to notice what master design teachers took note of when working with beginning design students. I started formulating a paper-based observation tool for teachers that they could carry around with them while visiting design teams. This 1-Pager, which eventually became a centerpiece figure of the 2012 JEE paper24 (pp. 748-749), aimed to be a primer for teachers to show them key practices of engineering designers while not overly taxing them in terms of cognitive load or physical weight. It aimed to help teachers “see more” when observing students’ design work and thinking, and to “prime” them to start building their own teacherly knowledge base as they became more familiar with engineering design activities, with what worked well and poorly with their students.

Even the earliest versions of what was then called the “Design Strategies Table” sought to alert teachers to beginners’ design habits of mind and practices, and to contrast these with what more experienced designers think and do. The basic structure of the table, which eventually was renamed the “Matrix Table”, was to provide a separate row for each of a number of prototypical engineering design strategies. The first column would present a contrasting title for each strategy or practice, followed by two columns that provided contrasting statements depicting how naive versus informed designers did them.

While the columns of the table were relatively stable over time, the table’s rows underwent regular revision. Initially, the rows included mainly collections of beginning designers’ habits of mind or preconceptions with no strong linkage to any of the many design process models. Also, the research base that I used to support these ideas came mainly from my thesis work that looked at naive, novice and expert designers doing two investigate-and-redesign tasks, and my work on the Design in the Classroom project.

I did many iterations of this table with various goals in mind – giving some thought to establishing the validity of its ideas in 2005; to offering clarity for teachers and members of the field (teachers, reviewers, funders, colleagues); and to support a “dialogue” between the 1-Pager and the journal paper so that one influenced and impacted the other. I sought to assess the validity of items that I included in the rows based on issues that included: how clear the item was expressed, its frequency in beginning designers’ behaviors, how large a problem the habit of mind might cause a designer, the degree of overlap with other patterns, whether the pattern was observable and evidence available for teachers to identify it, and whether instructional remedies had been reported in the literature to address it.

I recall during my first public sharing of an early form of the Matrix at the 2005 ITEA talk that a member of the audience suggested that I reorder the rows so that they roughly followed the sequence of practices found in a typical design process model – that person thought it would enhance the table’s usability for teachers, and render it easier for teachers to recall its contents. This suggestion is reflected in the next version, presented at the 2006 AERA, that uses icons to represent ordered design practices. Attempts were made to make the 2005 table (Figure 1) with its contrasting-set titles of beginning versus informed designer behaviors, to the 2006 version (Figure 2) that used icons depicting various design process steps to improve accessibility to teachers, and in 2007 a three-phase model of design that included fewer design steps (Figure 3).26
<table>
<thead>
<tr>
<th>Design Behaviors</th>
<th>Beginner Designers</th>
<th>Vs Informed Designers</th>
<th>Observations</th>
<th>Remedies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Idea Fixation / Fluency (Brainstorming)</td>
<td>BDs stick with their first design ideas, which they don’t want to let go of…</td>
<td>…Versus IDs who brainstorm lots of ideas, and throw out most of them.</td>
<td>• Audio/Video, Design Diary, Interview / check iterations for change</td>
<td>Easy, Objective</td>
</tr>
<tr>
<td>2. Problem Solving / Problem Finding</td>
<td>BDs believe that first thing to do is agree on big design decisions, and then implement them…</td>
<td>…Versus IDs who delay design choice until what's important is better known.</td>
<td>• Audio/Video, Prompted Recall, Interview / Easy/Hard, may not get said aloud</td>
<td>Subjective</td>
</tr>
<tr>
<td>3. Delayed Testing / Rapid Prototyping</td>
<td>BDs work in-depth on a single design plan for the entire time allotted before doing any tests…</td>
<td>…Versus IDs who build a range of mock-up solutions quickly to learn what does/don’t work.</td>
<td>• Audio/Video, Design Diary, Storyboard, Interview / Easy, Objective</td>
<td>• Video cases contrast 1st design moves of Novice/Expert</td>
</tr>
<tr>
<td>4. Constraint-Blind / Overly Constrained / Dream Designing</td>
<td>BDs pay scant attention to constraints of nature when designing (naive), versus being influenced by constraints too much (novice)</td>
<td>…Versus IDs who temporarily disregarding limits &amp; coming up with “dream designing” ideas.</td>
<td>• Audio/Video, Design Diary, Interview Q</td>
<td>E/H, can be determined thru Interview Q, Subjective</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Haphazard, Emergent / Systematic Designing</td>
<td>BDs approach design task as amorphous whole, working on whatever emergent problem is being faced at the moment…</td>
<td>… Versus IDs who break system into parts in orderly way, review what worked &amp; not, &amp; apply lessons learned to next iteration.</td>
<td>• Audio/Video, Design Diary, Interview Q</td>
<td>E/H, Subject/Objective, retelling makes work seem systematic</td>
</tr>
<tr>
<td>6. Generalized / Focused Attention</td>
<td>BDs’ generalized, unfocused attention is not centered on key phenomena in design tests…</td>
<td>…Versus IDs whose attention is focused on key criteria (how things fail).</td>
<td>• Audio/Video, Explanations</td>
<td>Easy, Objective</td>
</tr>
<tr>
<td>7. Accepting / Questioning Assumptions</td>
<td>BDs figure out task requirements and limits once, and then move on to design and build system …</td>
<td>…Versus IDs who periodically revisit initial assumptions.</td>
<td>• Design Diary, Storyboard, Prompted Recall</td>
<td>Easy/Hard, may get missed, Objective</td>
</tr>
<tr>
<td>8. Feature Creep / Keep It Simple Stupid</td>
<td>BDs continually adapt and add features to same idea until it becomes overly complicated…</td>
<td>…Versus IDs who follow the KISS rule to Keep It Simple, Stupid.</td>
<td>• Design Diary, Storyboard, Final Report</td>
<td>Subject/Objective</td>
</tr>
<tr>
<td>9. Unspoken / Reflective Designing</td>
<td>BDs perform design actions with little talking, planning or reflecting…</td>
<td>…Versus IDs who keep tabs on work metacognitively.</td>
<td>• Video, Prompted Recall</td>
<td>Easy-Objective, even though moments of reflection may get missed</td>
</tr>
<tr>
<td>10. Surface / Deep Drawings</td>
<td>When done at all, BDs drawings show surface features or things that would not work if built…</td>
<td>…Versus IDs who make drawings to show how parts connect, highlight critical design choices.</td>
<td>• Audio/Video, Design Diary, Storyboard, Final Report</td>
<td>Easy, Objective</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Forever Tweaking / Freezing a Design</td>
<td>BDs forever tweak and change the design, even during project’s last day…</td>
<td>…Versus IDs who setting a deadline after which no changes are be made to design plan.</td>
<td>• Video, Design Diary, Interview Q, Final Report</td>
<td>Easy, Objective</td>
</tr>
<tr>
<td>12. Linear / Iterative Designing</td>
<td>BDs view design as series of steps followed once until product is evaluated…</td>
<td>…Versus IDs who use iterative process to learn from feedback and strategies done as needed.</td>
<td>• Video, Design Diary, Storyboard, Final Report</td>
<td>Easy, Objective</td>
</tr>
</tbody>
</table>

**Figure 1.** The Informed Design Matrix: 2005
<table>
<thead>
<tr>
<th>Design Model</th>
<th>Beginning / Informed Design Strategy</th>
<th>Beginning Designers…</th>
<th>Versus Informed Designers who…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haphazard / Systematic Designing</td>
<td>…approach design tasks in haphazard ways, work on whatever problem emerges, without using any time management techniques…</td>
<td>…break problem into parts in a systematic way, review what did/didn’t work, apply lesson to next idea, manage project time &amp; tasks…</td>
<td></td>
</tr>
<tr>
<td>Problem Solving / Problem Finding</td>
<td>…see designers’ main work as first agreeing on how to solve problems…</td>
<td>…delay making design decisions until after doing effective problem finding…</td>
<td></td>
</tr>
<tr>
<td>Accept / Question Design Assumptions</td>
<td>…accept design assumptions once set…</td>
<td>…periodically question initial design assumptions…</td>
<td></td>
</tr>
<tr>
<td>Investigate Need</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skip / Do Research</td>
<td>…skip research and start in doing design work immediately…</td>
<td>…do research on prior art, do a product comparison, learn about materials, markets…</td>
<td></td>
</tr>
<tr>
<td>Unconstrained or Overly Constrained / Dream Designing</td>
<td>…pay too little or too much attention to design constraints…</td>
<td>…temporarily disregard limits when generating creative dream design ideas…</td>
<td></td>
</tr>
<tr>
<td>Idea Fixation / Idea Fluency</td>
<td>…fixate on first design ideas, which they don’t want to let go of…</td>
<td>…practise idea fluency by brainstorming ideas so that no single idea gets favored…</td>
<td></td>
</tr>
<tr>
<td>Depth-First / Rapid Prototyping</td>
<td>…work depth-first on single design plan for the entire time allotted…</td>
<td>…build a range of prototypes to learn rapidly about the problem &amp; what does and does not work in solving it…</td>
<td></td>
</tr>
<tr>
<td>Surface / Deep Drawings &amp; Descriptions</td>
<td>…describe &amp; sketch surface features of device that would not work if made…</td>
<td>…make deep drawings that show key features and how parts are connected…</td>
<td></td>
</tr>
<tr>
<td>Ignore / Balance Tradeoffs</td>
<td>Ignore tradeoffs by focusing on plus/minus of single design features…</td>
<td>balance tradeoffs of varying importance in making design decisions…</td>
<td></td>
</tr>
<tr>
<td>Unfocused Attention / Diagnostic Vision</td>
<td>…have unfocused attention that is not centered on critical areas of design…</td>
<td>…have diagnostic vision that can zoom in on out on critical areas of a design…</td>
<td></td>
</tr>
<tr>
<td>Feature Creep / Keep It Super Simple</td>
<td>…do feature creep, where they add to a design until it becomes too complicated…</td>
<td>…follow the KISS rule of elegance in design: Keep It Super Simple…</td>
<td></td>
</tr>
<tr>
<td>Unspoken, Tacit / Reflective Designing</td>
<td>…perform unspoken, tacit designing with little talk, planning or reflection…</td>
<td>…do reflective designing by keeping tabs on design work in metacognitive way…</td>
<td></td>
</tr>
<tr>
<td>Forever Tweak / Freeze a Design</td>
<td>…forever tweak a design and change it, even up to the project’s last day…</td>
<td>…set deadlines for freezing a design, after which no changes are made…</td>
<td></td>
</tr>
<tr>
<td>Design As Linear / Cyclic, Iterative Process</td>
<td>…view design as linear set of steps followed once until product is built and tested…</td>
<td>see and do design as a cyclic, iterative process where strategies are done as needed…</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1. Design Strategies Table**

**Figure 2.** The Informed Design Matrix: 2006
<table>
<thead>
<tr>
<th>PHASE OF DESIGNING</th>
<th>CONTRASTING STRATEGIES TITLES</th>
<th>WHAT BEGINNING DESIGNERS DO</th>
<th>WHAT INFORMED DESIGNERS DO</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Explore the Challenge</td>
<td>1. PREMATURE / DELAYED DECISION-MAKING</td>
<td>Treat design task as well-structured and make premature design decisions.</td>
<td>Delay making decisions in order to explore challenge, learn about critical issues &amp; do effective problem framing.</td>
</tr>
<tr>
<td></td>
<td>2. SKIP / DO RESEARCH &amp; INFO SEARCHES</td>
<td>Skip doing research and information searches, and instead start generating design solutions immediately.</td>
<td>Do research and information searches about the problem, including materials, prior art, users, product histories, etc.</td>
</tr>
<tr>
<td></td>
<td>3. CONFOUNDED / VALID INVESTIGATIONS</td>
<td>Do few early investigations or conduct confounded tests that build little understanding of the design problem.</td>
<td>Do valid investigations to help them learn quickly about design variables, users, materials &amp; how things work.</td>
</tr>
<tr>
<td>II. Generate, Build &amp; Communicate Ideas</td>
<td>4. IDEA FIXATION / IDEA FLUENCY</td>
<td>Fixate on first design ideas, which they won't let go of, and work depth-first in developing a single plan.</td>
<td>Practice idea fluency via brainstorming, sketching and rapid prototyping, and use gestures, words &amp; artifacts to communicate these ideas.</td>
</tr>
<tr>
<td></td>
<td>5. SURFACE / DEEP DRAWING &amp; MODELING</td>
<td>Describe &amp; sketch surface features of device that would not work if built.</td>
<td>Make drawings and models that show how parts connect and interact well, and models that test key features.</td>
</tr>
<tr>
<td></td>
<td>6. UNFOCUSED / DIAGNOSTIC VISION</td>
<td>Have a generalized, unfocused way of viewing tests and troubleshooting their ideas.</td>
<td>Use diagnostic vision to focus their attention while troubleshooting critical areas of the design plans and products.</td>
</tr>
<tr>
<td>III. Test &amp; Evaluate Solutions, Reflect on Practice</td>
<td>7. IGNORE / BALANCE BENEFITS &amp; TRADEOFFS</td>
<td>Ignore or pay too much attention to constraints and focus on + or – aspects of ideas without also thinking of benefits and tradeoffs.</td>
<td>Balance systems of benefits and tradeoffs when making design decisions, and use guidelines and rules-of-thumb to make these choices.</td>
</tr>
<tr>
<td></td>
<td>8. HAPHAZARD, LINEAR / ITERATIVE, MANAGED DESIGN</td>
<td>Design in haphazard ways, working on whatever problems emerge, or treat design as a set of steps to be done once in linear order.</td>
<td>Do design as an iterative process, improving ideas based on feedback, and use strategies in any order, as needed, in a managed way.</td>
</tr>
<tr>
<td></td>
<td>9. TACIT /REFLECTIVE THINKING</td>
<td>Do tacit designing when they think w little self-reflection &amp; monitoring of actions.</td>
<td>Practice reflective thinking by keeping tabs on design work in a meta-cognitive way.</td>
</tr>
</tbody>
</table>

**Figure 3. The Informed Design Matrix: 2007**

One of the challenges that came with writing the second half of the paper, which noted trends in various studies to substantiate patterns noted about beginning versus informed designers. The fields where design was being practiced were quite disparate (e.g., architects and engineers), and involved practitioners employing quite different kinds of design thinking and distinctly different ways of representing ideas. This synthesis/literature review nevertheless was needed as a foundation for the paper’s first-generation representation of design PCK, to increase the number and quality of pedagogical strategies for helping students improve their design capabilities, and to support the start/endpoints identified for each of the design practices. These later could, with more research, be framed as “learning progressions” for specific elements of engineering design, as was already being done with elements of scientific inquiry.

I was also sharing the table with teachers in 2005 and asking them for feedback. I was presenting the table at various talks; some appreciated the notion of informed design, while others, especially graduate students, found the contextualized literature review that linked familiar steps from a generic design process model to instructional remedies helpful by providing a big picture that still supported diving into in-depth searches by reading articles referenced in the narrative. Still, I as labored uphill pushing at what felt like a boulder that kept growing as I moved it further,
Through our collaborative inquiry process, we were able to see as a group all the ways use-inspired came into play: the motivation to create a parsimonious one-pager to assess design learning, the process of creating the Matrix, the iterative feedback cycles with trying out the Matrix with different users and substantiating patterns in existing research, and what it means to effectively communicate research into practice. These use-inspired, iterative cycles seemed to have emulated an “ever growing boulder” – where the effort to substantiate the ideas across a wide integrative path of design research was making the matrix bigger and bigger which conflicted with a desire for parsimony and use.

The key turning point for the paper regarding this Scholarship of Integration story came when I asked Robin Adams to review, help reshape it, so that it would be acceptable to the Journal of Engineering Education (JEE) - acceptable within current quality standards of publishing that didn’t seem to map to the essence of the work. A critical phone conversation came on January 22, 2010, when Robin was considering what role, including co-authorship, she was comfortable with in helping bring the paper to press after she re-read it.

Robin drew upon her own research in engineering design thinking and applied it to the task at hand and the challenges of publishing the paper in JEE. She noticed in her re-reading of the paper that it had a “problem framing” issue: “The framing should be that this is a paper that has both research and practical implications. The research implications are at the end that given this synthesis, here are the beginnings of a theory of informed design. For the practical implications, here’s a synthesis that connects research and practice to a number of tools to think about design teaching.”

Case 3b: Design Teaching and Learning

In the following story, Robin, an associate professor in engineering education continues the story of Case 3a and describes her “serendipitous” experience with reasoning through and articulating an SOI approach for the Informed Design Matrix paper. Within the story are key SOI features she shared as part of our collaborative inquiry process. Many aspects build on experiences evident in the previous cases (e.g., use-inspired motivations and principles, iterative and generative translational work, involving systematic literature review but not defined as one, and straddling Boyer’s Scholarship of Discovery and Scholarship of Application); some aspects delve deeper into the co-evolutionary features of the process and challenges of communicating this work as scholarship.
Even though I was well versed in the literature (I had just completed my dissertation on cognitive processes of iteration in design), I quickly realized I was in trouble. Design has no single home; it is an unbounded space spanning different disciplines, fields and professions each with their own language, theories, methods, and ways of seeing the world. Keyword searches are exasperating: searching on broad terms like “design cognition” gives many thousands of hits, and picking specific terms reveals how terms are not consistent across communities or have different meanings. For example, problem framing is a key design concept, but as a search term will only scratch the surface. You have to expand searches by using similar terms like problem formulation or problem definition, but would still miss research that attends conceptually to the idea but doesn’t use the same terminology (e.g., designing from first principles, abstaining from early commitment, etc.). I adopted a serendipitous search approach – reaching out for work that uses different terms to bring back and unpack important features of design learning. The level of translational work required to abstract out study findings (that tend to emphasize features of doing design) and imagine features of design learning was overwhelming.

In frustration, I changed direction to conjecture, “what might design learning look like?” the goal of comprehensively translating design cognition research into use-inspired instructional tools remained elusive. When David asked for input on the Matrix paper, I had a “eureka” moment. Not only had he succeeded where I gave up, but he also offered a different framing of “use-inspired” as enabling design PCK as a way to bring together existing research.

My second reaction to the paper was, as David mentions, an issue of problematizing and framing: what is the intention of the Matrix and what went into its design that needs to be communicated and understood for publication or broad use? I kept asking myself: “research involves identifying significant problems that need to be addressed – what problem is the Matrix trying to solve, and what ideas shaped its development?” We worked together to pull out key pieces of the Matrix effort in terms of intentions and rationales for various techniques and design principles. For me, a key role of research is to articulate theoretical and practical implications. This created an ongoing dialectic linking a Scholarship of Discovery to a Scholarship of Application - connecting motivations for creating the Matrix, the work that produced it, and arguments about use and significance.

Through this process, I realized one way to frame the Matrix was to articulate the challenges that motivated its creation and how overcoming or resolving these challenges shaped its design. As described earlier, a significant challenge was the scale, complexity, and “many homes” quality of the existing design literature. A second challenge was navigating the literature to articulate relevant and applicable patterns of designing that would help teachers develop their “professional vision” - their design pedagogical content knowledge. I began noticing a tight dialectic between setting up the intentions for the work (the introduction and background sections) and articulating the approach for creating the Matrix (framework and methods sections).

We approached the challenges of navigating and bounding the literature around conditions of use. Bounding involved articulating a learning target that would be meaningful for K-16 teachers and students. David named this “informed designing”. I experienced this as an anchoring concept; a placeholder for bringing together research findings that could characterize this state of enhanced design performance and offer a means for selecting relevant research among the broader literature. This was a generative process of abstracting out, translating, and representing research findings in terms of the new (previously semi-defined) concept of informed designing. This helped me understand how the Matrix involved a literature review but could not be defined as one.

I started using the language of design principles in thinking about the other considerations that shaped the form and function of the Matrix. This also had a strong use-inspired perspective: a parsimonious representation of key ideas (prioritizing ease of use over comprehensiveness), and patterns that could be observable, recognizable and memorable for teachers. A key idea was to help teachers notice important differences between beginning and informed designing in ways that could prompt teaching remedies and enable student learning. A significant change that occurred during the final Matrix iterations was to expand from the 1-page representation to a 2-page representation to offer teachers a holistic design PCK view linking behaviors, learning goals and instructional strategies to help students develop as informed designers.
The process of communicating the Matrix presented additional challenges. As far as we understand, this is the longest paper the Journal of Engineering Education has published to date. While a goal was to create a parsimonious tool (the Matrix as a 2-page handout), it was equally important to “unpack” the ideas in the Matrix to make the contrast between beginning and informed designing useful, relevant, and observable. This involved bringing the literature review to life, providing a chain of reasoning between the Matrix as a tool and the existing knowledge base. Where did the ideas come from? Why are they relevant indicators of learning or performance? What explains the contrasts between observable patterns of beginning and informed designing? What might be instructional strategies to help students develop as informed designers?

While we were able to problematize the Matrix – explaining the reasoning embodied in the intentions, design principles, techniques, and implications for theory and practice – we still lacked a way of talking about this as a kind of scholarship. It didn’t seem to fit solely within a Scholarship of Discovery or be representative of other techniques (e.g., systematic literature reviews or quantitative meta-syntheses). I sought out frameworks that could speak to the essence of the work. I connected to learning progressions and while this helped me see the strengths of the Matrix as a conjectural model to structure further empirical work, it didn’t capture its essence. I discussed this issue with Jennifer Turns, who was visiting me while on sabbatical. Neither of us can clearly point to what prompted the connection, beyond both of us being predisposed to putting feelers out for different ways of talking about things. She offered the idea of Scholarship of Integration.

I explored the literature and found our effort to be surprisingly synergistic with the intentions, process, and outcomes of a Scholarship of Integration effort. It strongly resonated with: a process of bringing together disparate pieces of knowledge of design cognition and learning into larger intellectual patterns (an integrative synthesis of key performance dimensions around an anchoring term of “informed designing”) to produce translational research (via design principles to translate and represent this integrative perspective into use-inspired tools). There were few (if any) worked-out examples; however, I could see how the framing we had been iteratively developing over time fully aligned with the general principles of SoI. Going back to the original challenge of problematizing the Matrix, the SoI framework captured the essence of the systematic reasoning, principles, and techniques underlying the Matrix design: the problem became the need for an SoI effort (based on the challenges we articulated) and the solution was to take an SoI effort (efforts to overcome or address the challenges articulated).

When we decided to write this ASEE paper, I pulled together a history of emails, notes, and paper iterations to reconstruct our story (123 iterations after the original draft). A **wildly iterative approach** doesn’t begin to capture the experience. The history data produced a 146-page document, which was whittled down to a shorter story for our collaborative inquiry discussions. **Iterations** spanned every aspect of the paper; nothing was left untouched. Through re-building this history, I began to see a broader set of patterns. First, I came to understand the Matrix approach as a **generative process of divergent and convergent cycles** – a process of **cross-disciplinary discovery** in itself. The principles guiding choices about **conditions of use** was a **dialectic** of process of selecting, reviewing, unifying, and translating the existing research in service of use-inspired tools. The **outcome** of this process was **new language** (informed designing) and **new tools** (the Matrix) – **new knowledge** in its own right. The “informed designing” concept served as an abstraction that could hold and bring together disparate and disconnected ideas – it came into being through this process.

Second, I didn’t realize just how much cross-talk existed between how best to represent the ideas in the Matrix and what it meant to **communicate the quality** of the Matrix as scholarship. Through our discussions, I began to see this **dialectic approach** as a **reflexive iterative spiral** of what we call in the design community, “co-evolution”, a recursive and generative process of concurrent problem framing and solving. Co-evolution occurs because problem formulations are ambiguous and solutions are many – and both co-evolve until a matched problem-solution pair emerges. This
resonates with Schon’s concept of **reflective practice**\(^{29}\), a back-and-forth generative process of producing actionable knowledge. Overall, I began to see many notions of design practice being made visible in our collective stories. If design involves making things under conditions of complexity and uncertainty, then perhaps we can think of SoI as recognizing and embracing a similar kind of messiness and a sense that the work may never be “complete”.

**Case 4: Reflection**

In this final story, Jennifer, a professor of human centered design and engineering, tells her experiences leading an SOI effort focused on reflection. As in the other cases, the story is followed by her description of the key SOI features revealed through the collaborative inquiry process. This story adds richness to many of the aforementioned themes (e.g., motivations, approach, use-inspired), introduces the notion of intertwined externalities in SOI efforts, and reinforces the idea that SOI work is “done as relative.”

As I write this vignette, many things cross my mind. Me telling myself, “we cannot make educators make students create portfolios.” Creating a big excel spreadsheet, xx columns and yy rows to organize what we were learning about reflection. Having to abruptly move from intellectually thinking about reflection to sketching out a 4 million project devoted to reflection. Creating an ASEE paper to capture what we had learned thus far. Embedded in these points is this: a story about a larger endeavor, middle sized project, and one paper. Each of these three efforts are scholarship of integration efforts. The story (or backstory) is not complete without all three.

In 2013, I was leading a series of efforts to synthesize lessons from research on the learning that students have when engaged in portfolio construction. Further, the goal was to move beyond portfolios – to explore more choices for the research. Reflection had been part of the work all along, since portfolio construction is a powerful tool for reflection, but we had reached a point where we wanted to see the work more broadly. Reflection was seen as the key. But just what is reflection, or what do we mean by it? How do we deeply understand but also go beyond the perspectives of Schon’s reflective practitioner or Dewey? Why does reflection matter?

Around this time, a reading from transformative learning theory about adult development provided an anchor. The reading, intriguingly entitled “What form transforms” spoke of adult development in terms of increasing capacity to move between subject and object, to move from being subject to an experience to having the experience as an object, to learn to step outside of situations, to stop being had by situations in order to have them. This led to a realization that such a movement is central to reflection.

The next part of the effort had both formal and informal aspects. The formality stemmed from a large spreadsheet we started creating—tracking theories related to reflection as well as activities designed to support reflection and mapping between these. The informality has to do with how we found items to incorporate. Comprehensively filling out the spreadsheet was an elusive goal, but having the spreadsheet provided a sense of power.

Not all SOI stories have externalities, but this one does. While we were enjoying our synthesis efforts and our attempt to produce something intellectually grand, we encountered an opportunity to do something organizationally grand. Ultimately the opportunity became the 12-campus Consortium to Promote Reflection in Engineering Education. To establish this consortium, we needed to move to elevator pitch versions of our grand synthesis efforts. We needed to retell our thoughts succinctly and to a new audience, and without the benefit of more traditional scholarly referents (e.g., a white paper, review cycle).

As it became clearer that our consortium might come to fruition, it also became clearer that we needed a reference document—that we needed to publish our ideas to date. The challenge was how to turn our myriad of ideas into one paper (e.g., what to carve off and for what audience). We chose ASEE since engineering educators were the ultimate audience of the work. As an ASEE paper, we had flexibility in terms of space (no page limits) and genre, but we also needed to find a modest story amidst our attempt to produce something we had playfully been thinking of as
intellectually grand. The ultimately accepted paper does not follow the genre of a standard research paper and is relatively long. Compromises and time shaped the document, and the document helped shaped the beginning of the consortium.

At the point of this writing, the reflection consortium is in its third year while the effort to explain and understand reflection continues. For this paper, a central question remains: what part was the Scholarship of Integration piece when the steps, stages, indeed the overall timeline, is so intertwined? Thinking about this issue has become relevant again as we seek to integrate work related to resistances to reflection and how to understand outcomes of reflection activities. The work continues.

While it has always been clear to me that the work described above was a scholarship of integration effort, the opportunity to talk it through drew out many features of what that meant. What was particularly salient through the collaborative inquiry discussions was the experience of some common challenges. For example, with regard to approach, finding materials can be difficult when you know you are working in a space where there is no shared vocabulary. Also, it is challenging to decide when something is indeed related to what you are trying to study. What started to emerge was a sense of the role of partial defining. For example, reflection involves attending to something (turning it to an object) in order to reflect on it. As a result, research related to attention arguably becomes relevant. As a related example, the issue of writing something for publication is also hard when you are working in a space without a shared vocabulary. This is both the challenge for scholarship of integration efforts and also an opportunity of scholarship of integration (i.e., the opportunity to establish vocabulary and/or guide the discourse).

This project also had some distinct features not completely shared with the other projects. First, the issue of the porous project boundaries seems relatively distinctive to this project. Since the project is situated in a history, it makes sense to the see the work situated at many levels. Which part is the SOI effort? Second, this story also features externalities that played a big role from a motivation standpoint, as well as in the project’s approach. This is interesting to acknowledge, and could potentially be framed as intentional serendipity. Third, what is potentially interesting about this project is the personal orientation. It is not clear that I chose reflection; rather it feels like reflection chose me and I simply needed to understand it. Such personal motivation can explain perseverance but perhaps may have led to challenges. This is a great reflection opportunity.

Discussion

In the previous sections, we have shared the stories of four scholarship of integration projects, and in one case, told two separate stories about the same project. The stories we have told are based on conversations in which we sought to identify common strategies and challenges across the projects. In the rest of this section, we identify and discuss one strategy and three challenges that were common across the projects. The assumption is that features common to our cases are likely to be relevant to other scholarship of integration efforts.

**Common strategy: Keeping the use and user in mind**

A discussion of the projects as use-inspired emerged early in our activity. As we unpacked this issue, we began see the role of audience and “conditions of use” as central to each of the projects. The informed design project was described from the beginning as a use-inspired effort. The
original motivation had been to help K-12 educators become aware of best practices of experienced design teachers, and make better use of research on design, specifically research on the what types of knowledge are involved in design and what it means to learn to design. In the other cases, the goal of providing something useful was salient to the research. We realized that each of us wrote implication sections that were quite extensive and covered both theoretical and practical perspectives.

Each of the projects offered tools for a specific audience. Sometimes the tool was an actual object (like the 2-page Matrix or a stakeholder-focused curriculum); sometimes it was a definition or redefinition (“reflection on experience”). Sometimes it was new language like “informed designing” or “enabling innovation” that sought to create a new space for research. The tool aspect was particularly salient in the design matrix work, but also centrally present in the work in innovation and systems thinking.

Digging deeper, issues such as which bodies of knowledge to include, how to describe particularly topics, and how to make a persuasive argument were experienced as tightly connected to the audience of the integration work. The role of the audience required us to think about the language we would use to describe findings drawn from different disciplines. The systems thinking project was written with aerospace engineering educators and researchers in mind and the informed design project was written for multiple audiences – teachers, educational theorists, and researchers.

As we sought to make deeper sense of the significance of the work as “use-inspired” and to address the issue of whether use-inspired was critical, we touched on the notions of backtalk and standpoint. Beyond just a constraint, the use-inspired nature of our projects seems to have driven the results through a “back-talk” mechanism. We each resonated to the idea of points where the goal of use-inspired drove us to go back into the bodies of research we were exploring to look again for relevant ideas. This contributed to the “iteration” aspect as “co-evolution.” We also came to appreciate the potentially foundational idea that all integration is done from a standpoint, and that this needs to be acknowledged.

**Common challenge: Communicating and publishing**

Challenges of publishing came up in all of our stories. Given the breadth and non-linearity of the projects, publishing issues included deciding how much or even which part of the work to put into a manuscript and how to best explain or present the work of the work. For example, in the reflection case, the goal was to fit a large notebook of ideas into a single ASEE paper.

The challenges went beyond such pragmatic issues. Issues of genre, reader expectations, and page limits factored into the stories. In the case on systems thinking, the author explicitly mentioned appreciating the space of an entire dissertation and the opportunity to use a non-standard format in order to present her work. In the cases on informed design and innovation, managing and meeting reviewer expectations also played a role. Failing to meet such expectations has led to rejection. In the case on systems thinking, the space afforded by a dissertation was a luxury: more pages did not cost more (except perhaps in ephemeral costs such as more to edit). In the case on informed design, more pages had a real cost. Because the *Journal of Engineering Education* charges authors by page, a longer paper is actually more expensive to publish.
So, how were these issues addressed? In addition to explicitly calling out the work as scholarship of integration efforts, we employed other strategies. Such strategies included embracing non-standard genres (i.e., naming, sequencing, organizing content in a way driven by the material to be presented), leveraging information graphics (e.g., the informed design matrix and enabling innovation model), and embracing the feedback process in terms of refining the work (even when the feedback was in the form of a rejection). In our conversations about the cases, we realized that additional strategies might stem from addressing a challenge related to rigor.

**Common challenge: Done as relative**

Everyone struggled with “when is this done?”. The discussion of done as relative emerged later in our conversation. In fact, the discussion was stimulated by a comment from David about “a part of the matrix paper that failed”. In the paper, readers were invited to “help extend” the matrix by providing suggestions, but no suggestions were received. This triggered a conversation about how a scholarship of integration characterizes done as relative. We explored terms such as “permanently unfinished”, “only ever partially finished,” and “dynamic” to capture what we experienced. Freddy’s tension of the back-and-forth dynamic of descriptive and prescriptive ends also spoke to this feeling, perhaps associated with the process of challenging paradigms. We spoke of a spiral, to capture the idea that one can continue to engage the broader knowledge across disciplines as an ongoing dialectic between the scholarship of discovery and the scholarship of application. While the “help us extend” request may not have worked out, the idea that these scholarship of integration projects can be extended or have a dynamic quality of being forever incomplete resonated for all of us.

Despite the seemingly “never done” nature of SOI studies, our stories illustrate different drivers and strategies for finding “partial” scholarly endpoints. Be it the desire to graduate, to submit a journal manuscript, or to prepare a grant, each of these stories has a partial ending point due to pragmatic constraints, but in reality these outcomes continue to be generative. Because of this, when engaging in this type of study, be prepared for not knowing, and for multiple iterations between “advancing the process” and “telling the story” along the way. In fact, telling the use-inspired story could be part of the reason why SOI studies seem to be so iterative. This iterative nature raises the question of stopping conditions – a concept that resonates in the design literature as a dominant feature of design tasks. If qualitative research has data saturation as a defining concept, what might that concept be for the types of scholarship of integration projects articulated above? This is one of the many questions we think deserve more conversation.

**Common challenge: Capturing rigor**

Rigor is a key issue in any form of scholarship, and capturing the rigor of our work was a challenge experienced in all of the projects. Sure, we knew we had worked hard, we had read broadly, we had crossed disciplinary boundaries, and we felt we had gained insight. But, did such features of our work represent rigor? The challenge of establishing rigor stemmed in large part from the observation that what we were describing did not map easily to other views of scholarship of integration such as meta-analysis and systematic literature review. The challenge of establishing rigor also stemmed from more pragmatic issues such as the duration of the projects (and the
challenge of record keeping) and the nonlinear nature of the projects (without a series of choice points, it is hard to tell a story).

Recognizing that establishing rigor would be an important part of our conversation, we attempted to map the work to the NRC guidelines, and found that the guidelines did not seem to resonate. We found that the principles suggest a linearity (perhaps unintentionally) that did not map well to our activities. For example, building a chain of evidence was part of the intertwining between an ongoing literature review and outcome (tool, definition, framework, language) – rather than a phase, it is an ongoing conversation. This suggests that establishing rigor for scholarship of integration projects, such as the ones presented in this paper, may be less about demonstrating that a particular process has been followed and more about highlighting properties of the knowledge that results. This also suggests that establishing rigor goes beyond a clear and bounded method section. Further discussion of rigor in scholarship of integration efforts is clearly warranted.

Concluding remarks

Given the expanding research base in engineering education, work to integrate new knowledge becomes ever more relevant. While many cite the significant value of the scholarship of integration, it is relatively underdeveloped and under-theorized. Some argue that this form of scholarship has been slow to gain acceptance as an integral activity in the professoriate, compared to other forms. The work of this paper has been to offer cases of scholarship of integration and to use those cases to address questions related to (1) strategies and challenges and (2) implications. We focused our discussion on the strategy of keeping use and audience in mind. We also focused our discussion on the challenges of communicating, publishing and capturing rigor, as SOI efforts live at the intersection of rigor and relevance, for which little to no guidelines exist.

We close with our question about implications: What implications do our cases suggest for individual researchers interested in trying to do this type of work, researchers wondering if this type of work is relevant to their topic, and a community trying to decide if and how to value this type of work? For individual researchers interested in trying to do this type of work, the cases presented provide a sense of what is entailed. For researchers wondering if this type of work is relevant to their topic, the cases provide a sense of what can emerge from such activity. Finally, for policy makers interested in advancing scholarship of integration, the cases suggest the need to explore what it takes to publish, fund, recognize, and reward such work. The effort to appreciate scholarship of integration warrants an ongoing conversation.

References


