Changing Conversations and Perceptions: The Research and Practice of Design Science

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Abstract

Although design science is a relatively young field, the impact of design research upon industry is evident in the literature, in the practice of design by academics, in the experience set of the authors. This chapter provides evidence of impact from three sources, two studies of design literature and one survey of design researchers. It is found that more than one third of design research articles, despite focusing on fundamentals, include engagements with industry, and, complementary, a majority of design researchers have patents, industry experience or both. These studies of design literature and design researchers change our perceptions of the impact of design research on practice and initiate a new conversation. In the context of research findings and models of transferring general fields of research to practice, design research impacts practice in a variety of tangible and long-lasting ways. Building upon these analyses, we develop a first set of guidelines for transferring design research to practice. These guidelines are illustrated by selected examples and outcomes from the authors' experiences. The frontier of design science, especially the impact on practice, is exciting and filled with unlimited potential. Changing conversations and perceptions is a critical first step based on the community's , building tremendous past successes. Through proven guidelines, we may realize our potential and create a sustainable ecosystem of transferring design research to practice.

1. Introduction

The belief that design research has little impact on practice is persistent. On the one hand, this criticism is often applied to all academic research efforts; on the other hand, it is largely a matter of perspective based on limited assumptions, narrow definitions, and stereotypical views. Few of such statements are clarified by a holistic consideration of the roles of design research, design science, and industry. How does knowledge transfer relate to our definitions of design science and design research? What are modes and rates of knowledge transfer? Does design research need to be commercialized to be successful, or is its impact on the education of the next generation of design practitioners more significant? As we reconsider these expectations and perspectives on design research, the impact upon practice becomes clearer.

The term ‘design research’ refers here to the scholarly inquiry that seeks to advance design by studying and improving it in systematic and scientific ways. More specifically, design research is the means to expand, test and operationalize the findings of design science. It includes both art and science, and is clearly identifiable in fields related to the applied sciences and the social sciences (Frankel and Racine, 2010). Distinguishable communities of design research include engineering and industrial design, architecture, urban and interior design, design computing, interaction design, and product and innovation management. Across these fields, varied perspectives exist as to the meaning and usefulness of design science (Gehlert, Schermann, & Pohl, n.d.; Gill & Hevner, 2011; Hevner, March, Park, & Ram, 2004; Järvinen, 2007; Venable, 2004) . To summarize these perspectives, a general description of design science includes the following features:

i. Applying the scientific method to study design and its epistemological elements as a practice, process, and human endeavor.
ii. Improving design practice and learning through the study of design principles across disciplines, including a stratification of formalisms, such as design rules, heuristics, and guidelines.
iii. Creating long-lasting knowledge and theoretical foundations from which design methods, processes, and tools may be developed and advanced.
iv. Integrating knowledge from disciplines, such as cognitive science, social psychology, anthropology, and sociology.
v. Connecting research, practice and technology development by integrating the above features.

From the traditional perspective that research can be characterized as a linear spectrum from basic to applied, design research has no logical or natural mapping to this spectrum. . More appropriately, we adopt the alternative representation of research as a two-dimensional space, defined by an axis for advancement of knowledge (basic research) and an axis for immediate application (applied research) (Stokes, 1997). The resulting space reveals three quadrants of interest: one for purely basic research, one for purely applied research, and one for research that advances knowledge and provides immediate applications. It can be seen as the ideal of design research to exist in this latter quadrant, contributing to both design practice and science.

One key implication of this representation is that bridging research and industrial, commercial or entrepreneurial applications is a two-way relationship. Very often new systems, products and processes spur, support or enable new fundamental questions that reveal new and valuable understandings. We consider here numerous examples of design research influencing practice from education and professional development to incubation and collaboration with industry partners. We define impact and influence as transfer of knowledge between design researchers and practicing designers. Knowledge transfer is not necessarily measurable and direct; it may take many forms, involving people, products, and partnerships.

1.2 Learning from others

Since design research is a relatively young field, we can learn from other traditions where the connection between research and practice is of special interest, such as medicine, management and education. Some main challenges in medicine include obstacles that health practitioners face in approaching the scientific literature, assessing the validity and practical relevance of new knowledge, and incorporating the appropriate results into their practice (Greenhalgh 2010). These skills are considered the basics of *evidence-based medicine*. The gap between what is known and what is done in medicine has also been linked to the overuse, underuse, and misuse of research output (Glasziou and Haynes 2005), with studies showing that research that should change medical practice is often ignored for years. Even when best practices are well known, they may be poorly implemented. Thus, there are several structural and systemic factors across health education, research, practice and regulation that result in insufficient support for research-related activities with practitioners (Embi and Payne 2013).

In management, scholarly research has become less conceptually and instrumentally useful to executives, managers, decision makers and teachers as demonstrated by a recent study that tracks top academic journals to identify articles with findings that are actionable by practitioners. The results of the study confirm a sharp decrease in the proportion of top journal articles that generate actionable knowledge from 1960 to 2010 (Pearce and Huang 2012). In education, dissemination approaches have been identified as a key weakness, creating the ongoing research-to-practice gap (Cook et al. 2013). These studies show that current dissemination methods fail to resonate with or influence practitioners due to the misalignment of outlets, including venues that target narrow communities of academic researchers and broader publications intended for practitioners.

Other relevant areas to analyze the impact of design research on practice include university-industry research collaboration (Bronwyn et al. 2001; Jonsson and Leven 2012), knowledge transfer and diffusion (Fiddaman et al. 2013), academic entrepreneurship (Grimaldi et al. 2011) and design policy (Raulik-Murphy 2010). Frameworks and models for transferring academic research to practice capture stages such as exposure, adoption, implementation, and practice of new interventions (Simpson 2002), or, as based on another model, awareness, acceptance, application, agreement, and adherence (Glasziou and Haynes 2005). Recently, Tabak et al. (2012) produced an inventory of 61 models to enhance dissemination and implementation of research in practice, categorizing them by construct flexibility, focus on dissemination or implementation, and a socio-ecologic framework that locates barriers at various levels: system, community, organization, and individuals (Holmström et al. 2009, Dang et al. 2011; Green et al. 2009, Lenfant 2003).

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To apply research findings in practice, companies need to perceive the competitive advantage of new knowledge. However, studies show that only a few companies tend to introduce new products or services (Design Council 2006). SMEs are highly vulnerable to competition and usually are the largest employers of new knowledge; however, multiple barriers prevent SMEs from investing in design, including management structures and lack of financial resources (Raulik-Murphy 2010), low capacity to absorb risk and uncertainty (Johnson et al. 1990), a mind-set of efficiency, and cost-cutting and incremental changes (von Stamm 2004). Currently, several countries have developed programs to help companies develop design capabilities. These programs aim to raise awareness through promotional activities such as seminars, exhibitions, awards and publications (Raulik-Murphy 2010).

In summary, (a) the research-to-practice challenges in design are shared by other fields and have been extensively studied; (b) despite notable exceptions, knowledge transfer can take up to 20 years; (c) challenges and opportunities result from structural characteristics at various levels including research fundings, industry strategies, market demands, academic promotion, and educational models; (d) professionals are likely to face obstacles finding, assessing and applying relevant information given the existing means for knowledge dissemination; (e) valuable research findings are likely to exist but have not been applied or are applied poorly (i.e., the gap between research and practice); (f) a wider range of models and guidelines are needed to cover the varied conditions in the design research-practice relationship; (g) strategic policies and incentives are needed to build bridges between design research and practice; and (h) different terms are used across cases and areas of study to refer to overlapping categories such as stakeholders including: industry, practitioners, non-academics, partners, clients, public.

The following sections provide quantitative results from sampling the design research literature and surveying the practical experiences of design researchers. The chapter concludes with guidelines for establishing and developing working relationships between practicing designers and design researchers and provides specific case studies from the authors' own research experience.

Context from Sampled Literature Analysis and Surveyed Researchers

Because many of our perceptions are founded in impressions from the literature and academics, we begin with three studies of design research. The first study considers the participation of industry professionals across the design research literature within the last two years, a sample of over 192 publications. The second study samples 134 publications in the same design journals since 1990 to determine the number of publications with industry involvement and the types of knowledge transfer occurring in design research. The third study provides a survey of the design experience of engineering design researchers in academia. The data from these studies support the encouraging view that there is a significant connection between design research, design researchers and design practice.

2.1 Investigating Author Affiliations in Research-to-Practice

We begin by evaluating close partnerships between academia and industry as evidenced by authorship affiliations of recently published articles in five top redesign search journals: Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AIEDAM), Journal of Engineering Design (JED), Research in Engineering Design (RED), Journal of Mechanical Design (JMD), and Design Studies (DESSTUD). While the main mission of each journal is primarily to present advances in design science, four explicitly include some industry relevance in their scope:

AIEDAM: "The journal is also interested in comprehensive review papers, as well as in *practicum papers* that describe original, major applications of state-of-the-art techniques to important engineering problems."

JED: "The journal publishes *pioneering best industrial practice* as well as authoritative research, studies and review papers on the underlying principles of design, its management, practice, techniques and methodologies."

RED: "The journal is designed for professionals in academia, *industry and government* interested in research issues relevant to design practice."

DESSTUD: "The journal publishes new research and scholarship concerned with the process of designing, and in principles, procedures and techniques *relevant to the practice* and pedagogy of design."

These mission statements include business and government as part of their audience, but limit their scope to research, with only one adding practice as a subject for publication. It would therefore be a hypothesis that few authors are practicing professionals outside of academia, with the exception of recent graduates. We argue that a promising number of authors are practicing professionals.

For each journal, the 50 most recent papers, or two most recent volumes (years) were analyzed for authorship affiliation. The final sample size was 192 design research publications. Authors from industry, the military, government or hospitals evidence the relationship between design research and practice and were tallied as industry professionals. Authors affiliated with a university or co-authoring with their academic advisors were tallied as academic professionals. While 174 papers were authored exclusively by academics, 18 had authors from industry, the military, government or hospitals.

This total of 9.4% of papers (for JMD up to 14%) represents strong partnerships, as publishing in academic journals is not a typical component of design practice. The fact that approximately 1 in 10 papers within the academic venue are written by authors affiliated with non-academic organizations is significant. We assume that this percentage of published research is of *high* relevance to industry, but recognize that authorship is just one indicator of practical relevance. The con-

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nection between practice and research exists in many forms, and the next section analyzes multiple indicators on a more holistic scale.

2.2 Sampled Literature Analysis: Research Transfer to Practice

This section considers evidence from the same five design research journals as the authorship affiliation study. With the perspective that archival publications are primarily an academic venue, we consider that authorship, case studies, acknowledgements and other in-text references to applications of the research are indicators of knowledge transfer between industry and research. Following from the sample of recent authorship, and the nature of design research, the hypothesis for this analysis was that there exists substantial knowledge transfer between research and practice. Figure 1 illustrates the procedure used to undertake the study, from sampling articles from the literature to analyzing industry connections.

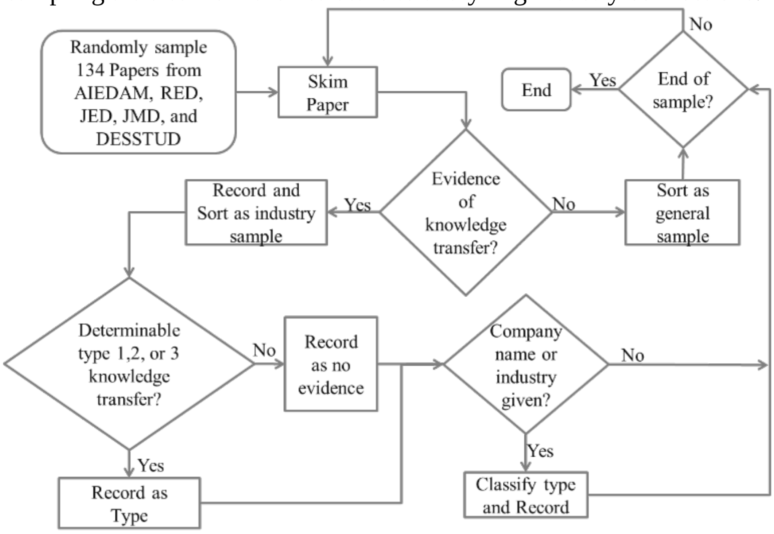

Figure 1: Sampling Procedure for Determining Knowledge Transfer

The publications were randomly sampled from each journal and from volumes published in 1990 or later. The year 1990 was selected as the first year all five journals co-existed. The number of samples from each journal was chosen to be proportional to the number of search results within each journal given the terms "design theory and methodology". For example, AIEDAM yielded 297 search results, while JMD yielded 159, RED yielded 248, JED 217 and DESSTUD 376. The lower proportion of JMD articles makes sense as JMD has a longer history of archiving research in mechanisms rather than design science. The final breakdown between journals was 16 JMD articles, 26 RED, 22 JED, 31 AIEDAM, and 39 DESSTUD for a total of 134 papers. Since 1990, these journals have archived over 5,000 publications with the keyword "design," and a statistically significant sample would be 96 articles.

After collecting the samples, each paper was sorted into one of two categories. Articles with no evidence of knowledge transfer between design and practice were sorted as belonging to the general sample set. Articles that implied or explicitly described knowledge transfer were considered to be part of the smaller, "industry sample." Similar to the authorship affiliation study, industry was defined as any non-university author, participant, collaborator, advisor, or sponsor.

Three directions of knowledge transfer between industry and research are possible and were classified as one of three types: Type 1–practice informs research; Type 2–research informs practice; or Type 3–research and practice inform each other. Practice informing practice and research informing research are not considered. Since this sample represents archival publications within the academic research realm, type 2 knowledge transfer is difficult to analyze from the literature. Academic journals are necessarily transferring knowledge to academia, at a minimum, being read by reviewers. Therefore, type 2 is only possible if the publication does provide evidence of the application or needs of the sponsors. It is shown in the later sections, through examples of the authors' own research e.g., in Section 3.2.3 regarding the Ford and DTM case, that type 2 knowledge transfer may be fairly common but is, at times, only evident in the acknowledgements of publications.

Evidence of knowledge transfer was found in one of three ways. First, if an author was affiliated with a business, defense or non-university institution, the paper was considered to exhibit type 3 knowledge transfer, regardless of the authors' academic ties. Second, if the text referred to a study of practicing design professionals, applying a technique within a company, or consulting with expert designers, the paper was considered to exhibit type 1 or type 3 knowledge transfer. Finally, if the acknowledgements of the paper mentioned a business, defense or non-university institution as a sponsor or consultant, the paper was considered to exhibit type 1, type 2 or type 3 knowledge transfer.

After sorting the samples and classifying the types of knowledge transfer, the type of industry was noted to discern trends in the types of industries that design addresses. A few industry references within the texts and acknowledgements did not specify the companies or fields. These were not considered.

Using these definitions and sampling procedure, it was found that 39% of articles in the top five design research journals exhibit evidence of knowledge transfer between research and practice. Given the sample size, the 95% confidence interval for this sample is ±8%, meaning that between 31-47% of published research is shared with industry. In comparison with our findings from other research fields, and the consideration that publications are primarily academic in nature, this number shows substantial collaboration between the supposed "silos" of research and practice. Furthermore, the variety of industries engaged in design research in encouraging. Although a third of the partnerships were with defense, aerospace or automotive applications, consumer products, industrial products, electronics, banking, electronics and software were all represented in the two-third majority.

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Given the three types of knowledge transfer, 11% of papers were type 1 knowledge transfer (studies of designers), 20% were type 3 knowledge transfer (practice and research inform each other), and 7.5% were undeterminable as type 1, 2, or 3. Most type 1 knowledge transfer was evident within the text as part of the experimental methodology. We argue that studies of designers can influence design practice directly, as the participation in an experiment becomes part of the experience of the participant and that experimental procedures can teach new methods to practicing designers. Nevertheless, a conservative approach was taken in considering these interactions, limiting the transfer to type 1, practice informing research.

For type 3 transfers, many of the samples included industry authors. Of the 124 articles, 22 (17%) were authored by non-academic professionals. Five articles (3.7%), some with purely academic authorship, explicitly mentioned that their research application was part of the development of a commercial or industrial product. Even if we consider that non-academic authorship does not indicate immediately applied research, one in 27 publications features research that describes immediate industry applications. These results are in addition to the type 2 knowledge transfers (research informs practice) not reported within the literature.

It is important to note that connections to design practice are not always central to communicating results of design science and research. From the literature, , the transfer of design knowledge between academia and industry is often paired with clear impact on marketed products or processes, and the exchange of expert designers, either as new-hires or authors. In Section 3.2.1, an example is given of total knowledge transfer; a graduate student is hired by the partnering corporation and immediately asked to train the rest of the company in the newly devised methodology. In reported results, only the dollar savings of the research case study are mentioned, and only in one sentence of the article (Wood, 1998). The implications are at least twofold: the value of design research to practice is not typically conveyed within academic venues, and academic literature provides a conservative representation of the impact of design research on practice.

2.3 Study of Design Researchers and Practice

This section considers ways that certain cross-sections of leaders in the engineering design field are engaged in design practice. The stereotypical hypothesis is that academics, and more specifically professors, lack practical experience. This study provides evidence to refute this hypothesis. The basis of the study is a set of demographic and technical questions that were not intended for this anthology (Krager, et al., 2011). The participants were leaders in the field and were asked to complete a survey as part of the application process for a past National Science Foundation (NSF) Civil, Mechanical, and Manufacturing Innovation (CMMI) sponsored workshop on individual and team-based innovation. These participants represent a set of domain knowledge experts in engineering design, and, as such, provide the possibility for key insights into understanding the current state of innovation, at least within this knowledge domain. The technical questions as part of the study include Likert-scale agreement and disagreement queries, in addition to a set of short answer questions. These multi-faceted questions support analysis by both quantitative and qualitative research methods. These questions were developed through a collaboration among the authors and participants of a workshop (Schunn, *et al.*, 2006) which included experts in the fields of cognitive psychology, social psychology, and engineering design. Through this approach, the intent is to investigate an individual's perception and knowledge of design research and methods across demographics.

Survey Question: **Profession**		*Survey Question:* **I have consulted for companies on their engineering design work…**	
Engineer in Industry	0 Respondents	Never	10 Respondents
Professor	34 Respondents	Less than 1 year	5 Respondents
Lecturer	0 Respondents	1-5 years	13 Respondents
Research Scientist	3 Respondents	More than 5 years	9 Respondents
Other	1 Respondents	No Response	1 Respondents
Survey Question: **I have worked in a company doing engineering design work…**		*Survey Question:* **I am a named inventor on patents…**	
Never	5 Respondents	Never	17 Respondents
Less than 1 year	9 Respondents	1 time	5 Respondents
1-5 years	21 Respondents	2-5 times	12 Respondents
More than 5 years	1 Respondents	6 or more times	1 Respondents
No Response	2 Respondents	No Response	3 Respondents

Table 1: A Sample of the NSF CMMI Survey Questions and Responses

Three categories define the study's construction: (1) demographics of the participant group, (2) technical components with quantitative assessment, and (3) short-answer questions. The first section of demographic questions, shown in Table 1, included characteristic data as well as the participants' professional histories, and is the focus of the inquiry here.

The survey was administered to 42 participants with 38 completing responses. The results indicate that the backgrounds of participants were broad, but the vast majority is well-founded in design education. Approximately 90% of the participants were engineering professors. The participants were well-distributed by age. The largest group, 42.1%, was in the range of 30-40 years old. Nearly as many participants aged 40-60 years (38.9%) were represented, while 18.4% of those surveyed were in the 20-30 year range.

The experience-based questions provide interesting insights into the professional activities of the participants. Fifty percent (50%) of those surveyed are named inventors on patents. This number is high compared to the percentage of named inventors across engineering faculty in general. A large number of participants had consulting (71.1%) and industrial experience (81.5%). Additionally, 71.1% have taught a product design course, and 63.1% have developed tools for innovative design. These results indicate that the participants were well-versed in the range of activities, research, practice, and education, typically engaged by design researchers in academia. The participants included markedly high experience of design practice in terms of consulting, industrial experience, and the development of intellectual property. They also were heavily engaged in developing tools for innovative design. Indirectly, these results indicate a strong association of design practice and design research. The participants appear to practice design as an integral component of their academic work, which should correlate to a higher potential of transferring their research to practice.

The evidence from this survey and the literature samples debunk a number of myths. Researchers do engage industry. Industry professionals do participate in academic venues, despite practical time constraints and other commitments. Furthermore, many design researchers have experience in practice as consultants, industry employees or both. It is noted that this evidence is limited to academic venues. Section 3 addresses the impact of design research on practice more generally, from the perspective of guidelines and with more specifics from case studies.

3. Findings: Transferring Design Research to Practice

In this section, we describe a set of cases where design research has been successfully transferred to practice. These cases represent just a few of the experiences of the authors, and include the goals of the design research, details of outcomes for practice, and insights derived from the experiences for developing impactful transfer of design research to practice, including any of the three types of transfer as discussed in the previous section. These examples were selected to illustrate a number of guidelines and mechanisms for impacting design practice.

3.1 Guidelines and Platforms for Impacting Design Practice

To begin our discussion of actual findings and cases, a collective assessment of design research and the platforms for meaningfully engaging industry and practice is carried out. We begin this assessment by identifying similarities across the sample of academic papers. Building upon these findings, we assemble the results from literature findings, workshop studies of design researchers, and the experience of the authors, and provide the list of guidelines shown in Table 2. Guidelines here suggest specific courses of action that can meaningfully result in long-lasting and sustainable transfer of research to practice, and are but a first step based on decades of activity within the design research community. The first column in Table 2 lists each guideline, where the lexicon is an action to be undertaken on the part of the design researcher and in concert with partnerships in practice. The subsequent columns of Table 2 list known and expected outcomes from each guideline, in addition to suggested mechanisms for implementing a guideline. The adaptation of multiple guidelines creates a portfolio of rich connections for deep relationships in practice. Combinations of implemented guidelines across and between international design programs have the potential to build on past successes of design research and develop an ecosystem of even more dramatic innovations for the grand challenges at the community, national, and global levels.

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Table 2. Guidelines and Platforms for Design Research Engaging Design Practice.

Guidelines	*Outcomes*	*Mechanisms*
1. Connect direct value	New products, services, systems, profits, markets	Collaborative development, residency, consulting, sabbatical
2. Partner with product development firms	Transfer of knowledge, talent	Employee, intern, residency, sabbatical
3. Assess industry processes	Diagnostics, trust/relationships, strategy	Consulting, intern, residency, sabbatical
4. Incubate companies	State-of-the-art, design-driven companies	Research lab, incubators, technology parks, hack-a-thons, exhibitions, contest, space, fabrication labs,
5. Invent within design research	Product, case study, accessible research in the language of practice, enterprise, process, material	Thesis, dissertation, industry sponsored project
6. Collaborate with industry partners as PIs	Funding, joint investment/commitment, new methods	Employees, graduates, grant agencies, challenges, industry fair
7. Practice design	Recognition, portfolio,	Competitions, installations, IP, exhibitions, awards,
8. Commercialize methods and techniques	Products of design research, such as finite element analysis (FEA), failure modes and effects analysis (FMEA), design for manufacturing (DFM), design for assembly (DFA), House of Quality (HoQ), Six Sigma, Design for Six Sigma (DFSS), Lean Design, computer-aided design (CAD), Optimization, Theory of Inventive Problem Solving (TRIZ / TIPS), Rapid Prototyping.	Companies, software, certification,
9. Brand and disseminate	Accessible research in the language of practice, brand, awareness	TED talks, periodicals, blogs, social media, books, manuals, standards
10. Develop standards in design	Verification, assessment, endorsements, expert judgment, standards, guidelines, taxonomies, ontologies	Expert witnessing, testing standards, government grants,
11. House practitioners on campus	Relationships, ideas, immersion of practice in research	Chairs, industry labs, donations, residency, advisory panels, industry days, seminar series, industry consortium, hiring adjunct faculty, project advisors/judges
12. Engage practitioners in professional development	Transfer of skills, trust/relationships, reputation,	Continuing and lifelong education programs, targeted at the module or degree level, internal industry education programs, joint Masters programs, reverse-residency/sabbatical, MOOCs (Massive Open Online Courses)
13. Immerse students at all levels in design-based learning	Next-generation design engineers, loyalty/pride/identity, strong design fundamentals, graduates with skillset that maps design research to practice, Exposure to real world settings	Design education programs at the levels of K-12, undergraduate, graduate, professional Masters, PostDoc, and research assistants, MOOCs, UROPs, capstone, service based learning, student

		groups/clubs, field visits (O Lab), company visits

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3.2 IDRP Cases

Building upon the guidelines and platforms described in Table 2, we selected five particular cases to illustrate successful integration of design research and practice. These cases provide details on how a subset of the guidelines and platforms listed in Table 2 may be realized in publishable and non-publishable ways. We begin with a case of an automotive partnership in which an industry need was met by developing new design tools. Then we consider the development of fundamental design language that was applied to reverse engineering, automotive design, the design of manufacturing machines, and international standards. Finally, we also consider the value of cases with educational elements. One research project realized value in training future air force leaders in design research thinking while others include curricular and extra-curricular experiences. All of these cases were part of the development of commercial products.

3.2.1 Design Methods Development and Transfer: Automotive Industry

In this case, we consider the guideline (#1) of connecting, initially and directly, with the bottom-line business of original equipment manufacturers (OEMs) and part suppliers of the automotive industry. The outcome of this case was the development, testing, validation, and transfer of design methods to practice. The research project began by identifying design processes and particular products which the industry identified as critical to their business and in need of radical, innovative improvement and advancement. This case illustrates an actual design method transfer, developed and marketed products, and the process by which these results were realized.

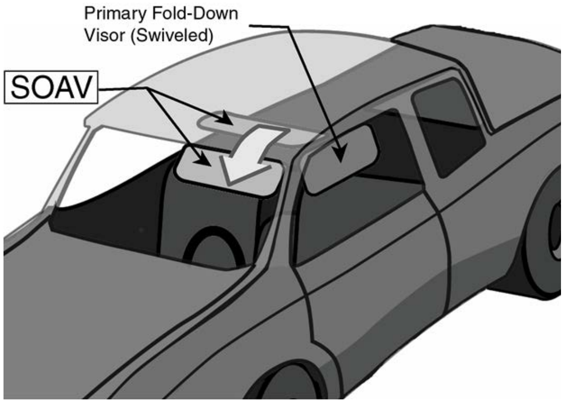

Figure 2: Slide-out auxiliary visor (SOAV)

Methods for design for assembly, novel part combination, and part reduction were developed as part of a Masters' thesis project and graduate internship, motivated by direct relevance of the authors' research lab's interest in developing methods for redesign and innovation, and our industrial partner, Prince Corporation's desire to simplify and reduce assembly costs for their systems, such as a slide-out auxiliary visor (SOAV) (Lefever, 1995; Lefever & Wood, 1996; Greer, 2002; Greer *et al.*, 2002, 2004). The SOAV was part of an overhead ceiling unit produced at high production volumes for a luxury automobile manufacturer. The SOAV unit supplemented the traditional fold-down visor by allowing the driver to shield light coming from both the side and front of their vehicle. While the traditional fold-down visor, in the swiveled position, shields light coming from the side, the SOAV, being contained above the headliner, translates out and rotates down to block incoming light.

Prince Corporation was originally requested, by the automobile OEM, to design this automotive subsystem, complete through tooling and pre-production, in a period of two months. This very short cycle time provided very little time for iteration. None-the-less, Prince undertook the project, and produced a very robust, reliable, and mechanically novel SOAV, while following sound design principles, such as top-down assembly of all components and internal-force symmetry to provide a self-balancing and anti-binding slide-out system. After the initial design and first-run production, the SOAV assembly consisted of 40 parts, more than necessary to carry out the required functions and a ripe opportunity for reducing manufacturing cost, developing innovative redesigns, and production time savings.

Prince Corporation and the authors developed an agreement to undertake this project in terms of design research and product development, where the goal was to affect the bottom-line business of the company. The outcomes of the research project were four-fold: significant cost savings in the form of a redesigned SOAV (guideline #1 and #5), creation of two new methods for novel component combination and parts reduction, introduction to and training of engineers at Prince automotive (guideline #12), and education of over 4,000 graduate and undergraduate engineering students at the University of Texas at Austin (guideline #13). These outcomes exclude the students and practitioners outside of the University of Texas at Austin who are taught the reverse engineering methodology in Otto and Wood (2001).

Two methods were developed as significant extensions to Boothroyd and Dewhurst's (1980) Design for Assembly (DFA) method and integrated into a reverse engineering and redesign methodology being constructed by the authors. Boothroyd and Dewhurst's (1980) DFA method was well known at the time for evaluating the ease of assembly of a product. Although methods for DFA existed, there was little work on extending the evaluation of a product to redesign possibilities. The project therefore fit well into the researchers' long-term goal of creating a reverse engineering and redesign methodology and toolkit.

Information about the processes and methods developed to accomplish the task of part reduction are well-documented in the literature. The account here serves to provide the reader with an overview of the academic results, especially in terms of actual design research transfer to industry and implementing guidelines for meaningfully accomplishing this transfer.

One method added to the toolkit is referred to as the Subtract and Operate Procedure (SOP). Many products are composed of redundant parts or solutions that can be eliminated. The SOP is a five step procedure for removing individual components of the product assembly, operating the product through its full range of functionality with the component missing and analyzing the resulting operability.

The procedure is then repeated by replacing and removing components, combinatorially, one component at a time, and discovering redundancies in the system. The type of redundancy describes whether the component or part can simply be removed or replaced by parametric redesign of another component.

Another method added to the reverse engineering toolkit is referred to as Force-Flow (or Effort-Flow) Analysis. Force flow (or effort flow) diagrams represent the transfer of energy, effort, or force through a product assembly. Each component is represented as a node connected by arrows indicating the directional flow of forces. Wherever flows require relative motion between components, an R can be placed to denote the edge of a group of components. A group of components surrounded by "R"s then become candidates for part combination.

For Prince Corporation, the results of this research produced an SOAV redesign with fifteen fewer components and identical functionality. Force flow analysis alone can be credited with nine component combinations, part reduction, and novel component redesigns. The part combinations and reductions also reduced manufacturing and vending costs while allowing assembly workers to be shifted to other assembly lines. The result was millions of dollars of savings for manufacture of the SOAV alone.

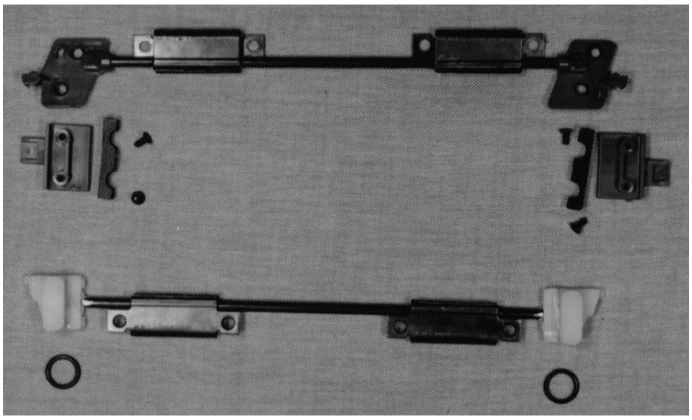

Figure 3: Partial SOAV Initial Components and Redesign

The established cost value of this work led to the hiring of a lead graduate student from the research lab after completion of his thesis. Within two months of working at Prince, this graduate had trained the remainder of the engineering team at Prince in the reverse engineering and redesign methods being developed at the University of Texas. This application of guideline #12 was initiated by Prince.

The Masters and PhD students who developed these methods and associated tools were not the only means of transfer of this knowledge to daily practice. The reverse engineering and redesign methods were also included in the development of a textbook for Product Design. The relevance of such work is vastly important, if we consider the University of Texas alone trains over 250 engineering students in these methods annually.

3.2.2 Professional Development and Design Theory / Method Transfer Program: Example with the US Air Force

In this case, we describe an outcome of performing and transferring design research with a variety of organizations as part of the United States Air Force. The primary mode of transfer was in the form of combined sponsored research and professional development programs (guideline #12), where industry professionals directly applied developed design methods as part of their technology development projects. Other modes included university-level education programs and fundamental design research projects with the research entities of the Air Force.

The project was initiated through the contact of the authors with a chief scientist office in the US Air Force Research Laboratories (AFRLs). A meeting was arranged to pitch recent advancements by the authors in design research. During the first meeting, design research results were shown, and their impact described with industry examples and outcomes in the commercial marketplace. While the first meeting generated good discussions and intellectual interchange, the core of the design research did not resonate with the needs of the AFRL chief scientist, and there was a general decision not to pursue the proposed work. However, the chief scientist invited the authors back for another meeting the following day, where the authors would be afforded another opportunity to re-scope the ideas, especially in the context of the applied missions of the AFRL. The authors mapped the understood missions of the directorate, and realigned the design research and associated research methodologies. The idea of Transformation Design Theory was born (Singh, et al. 2009), and pitched to the chief scientist as a fundamental design research project, an applied development initiative of innovative systems, and a professional development project to train and transfer potential findings to various groups in the Air Force. This project was welcomed, and a seven year research relationship began between the collaborators.

Transformers research is a collaborative project between the University of Texas at Austin (UT), the US Air Force Academy (USAFA) and the Air Force Research Labs (AFRLs), such as the Munitions' Branch in Eglin FL. The Air Force was interested in this research for three advantages, (1) transformers present an exciting opportunity for innovative concepts (2) working with the air force academy ensures training of the next generation of officers in both technical and creative aspects of problem solving (3) the collaboration resulted in new micro air vehicle (MAV) designs. Through the first two years of collaboration, a transformer design theory was developed, where "transformation" is defined to be the act of changing state in order to facilitate new, or enhance an existing functionality. Based on this definition, a "state of a product" is defined as its specific physical configuration in which the product performs a primary function(s). Ultimately, three fundamental principles and a number of critical facilitators were presented and illustrated. These principles and facilitators form a budding theory of transformation in design (Singh, et al., 2009a&b; Weaver, et al., 2010; Skiles, et al., 2006; Singh, et al., 2006a&b; Singh, et al., 2007; Weaver, et al., 2008; Wang, et al., 2009; Camburn, et al., 2010).

Building on the theoretical findings of transformation, a number of design ideation techniques were developed, as well as realized MAV systems. Two exemplar MAV design objectives were to develop a gust resistant wing and a stowable MAV. The MAV is a replacement for current unmanned aerial vehicles that weigh 1kg or greater, and is equipped with autonomous navigation and cameras with real time video transmission. Before implementation of transformer techniques and the collaboration of USAFA and UT students and researcher, the MAV was highly susceptible to wind gusts and originally versions included a rather large stowage cross-section. The application of the transformation principles allowed the MAV to remain lightweight, have a compact collapsible structure, be able to complete hundreds of missions, and remain inexpensive enough to be expendable.

The gust resistant wing concepts improved resistance to wind gusts by over 50%. Three concepts were developed and tested using experimentation and analytical modeling: (1) ported wings, (2) elastically hinged spoilers and (3) variable dihedral angle. The ported wing concept consists of "ports" or small cut-outs spaced out along the wing span acting to reduce lift by separating air flow. These mitigate the effects of common upward gusts of wind through either passive or active mechanical actuation. The elastically hinged spoilers concept consists of multiple sections of hinges on the trailing edge of the wing. These flap-like spoilers can be lifted independently of each other by the wind gust reducing the area of wing creating lift, resulting in separations similar to the ported wing's cut-outs. The dihedral angle would be in combination with each of the other concepts. By raising the wing tips above the wing's root, the stability of the MAV can be increased. Each of these concepts was implemented in wind tunnel testing and flight tests. All concepts improved gust resistance of the MAV. The addition of rectangular ports located close to the trailing edge of the airfoil have been shown to reduce the lift associated with vertical gusts by as much as 50% while reducing overall drag of the MAV.

Figure 4: Prototype of Ported Wing MAV

A number of stowable MAV concepts were developed using the transformer theory and associated ideation techniques. As one example, a stowable MAV design applies the analogy of a slap bracelet, creating a bi-stable wing structure. In its active state, the wing is spread at the full wingspan. In its stowing state, the wing is coiled tightly. The "Slap Bracelet" concept offered multiple benefits: ease of use, speed of deployment, low weight, feasibility, and novelty. The redesigned wing has two stable configurations, shown in Figure 5: (1) fully extended in the shape of a wing and (2) coiled alongside the fuselage. The bi-stable, carbon fiber wing is constructed such that a natural curvature exists in both the transverse and longitudinal directions. Because the wing can only curve in one direction at a time, the wing is always at a high-energy state in one dimension. The wing, in this

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view, is always stressed in either the longitudinal or transverse direction. The transition between states occurs when the wing's cross section is flattened in one direction.

These example applications of the design research in practice are but a few that resulted from the collaboration. Through the development of fundamental design theory, associated design methods, and working systems at the core missions of the partner (AFRL), a long term, trusting relationship was developed. In fact, this relationship expanded to a number of other Air Force entities, including professional development programs for Air Force personnel. These professional development programs focused on a wide range of design processes and methods, including transformer theory and ideation techniques. They also included rapid response development through the Air Force's Commander's Challenge Program, the teaching of Air Force officers and civilian personnel in this program, and the teaching of cadets in various United States Air Force Academy programs.

Figure 5: Slap Bracelet Wing Concept

3.2.3 Design Languages: Government Standards Organizations

In this case, we consider collaborations between various academic groups carrying out design research and the collaboration with counterparts in government standards organizations, such as the National Institute of Standards and Technology (NIST) in the United States (guideline #10, as well as guidelines #1, #6, and #12). The outcome for this case concerned the aggregation of different efforts of design research to develop a more comprehensive taxonomy and language for design that could be expressed as a working standard with greater exposure and connection to industry.

The authors' work with NIST, Ford Motor Company, and Desktop Manufacturing (DTM) Corporation originated from a National Science Foundation (NSF) Young Investigator Award, the observations of a Masters' student's research, and networking through the design research community. The NSF award required industry sponsors to support the research. Ford was interested in design for six sigma training, development of advanced manufacturing approaches, and the design of innovative automotive subsystems; and DTM wanted to model solutions to their novel additive manufacturing technology, the selective laser sintering process. Both companies were interested in modeling their products and connecting these to functional requirements and customer needs to create more innovative and robust designs. These goals fit into the long term dream of the investigators to create design methods and techniques, but the first step was not obvious.

Step zero was to review the functional knowledge available. A Masters student and doctoral candidate set about studying a wealth of products and recorded functional models available at UT, the archive of student reports from senior level design courses and design work with industry. After studying and analyzing these reports, the investigators were struck by the lack of coherent language between reports to describe products and their functionality (Little et al. 1997; McAdams et al. 1998; 1999; Stone et al. 1998). A common language was missing and would greatly aid in verbalizing, visualizing, sharing, architecting, and analyzing designs. The functions and flows could then be reliably connected to functional requirements, customer needs, and the creative generation of design solutions.

The resulting research goal was to create a common design language with a focus on the mechanical and electromechanical domains. This language, termed a *functional basis*, consists of a set of functions and flows with the intention of comprehensively describing the mechanical design space (Stone et al. 2000; Otto & Wood 2001; Hirtz et al. 2002). The functional basis has been shown to increase the repeatability, consistency in detail, and correctness of functional models created by a variety of designers (Kurfman et al. 2000; 2001; 2003; Wood & Greer 2001).

As an example of industry application, the functional language was presented by the authors as part of a five day design for six sigma training course at Ford Motor Company. The functional basis further enabled Ford to relate customer needs to functions and identify modules requiring increased robustness. Functional modeling was received with great enthusiasm and the results showed that the functional basis is useful for modeling the large-scale systems developed by Ford.

At DTM Corporation, the need existed to evolve process and machine subsystems as part of solid freeform or layer-based manufacturing. The functional basis was used to model system-level processes, subsystems, and components, ultimately leading to new subsystem concepts and improvements in precision surface control. After two years of development of the functional basis, it was presented at the American Society of Mechanical Engineers (ASME) International Design Engineering Technical Conference (IDETC). A NIST researcher, Simon Szykman, was presenting similar work to create a language for functional models of designs to be used in software. A collaboration was developed between the researchers from academia and NIST, where there existed a willingness to combine efforts.

Working with Ford, DTM, and researchers at the University of Missouri-Rolla, a large number of product models were completed over a three-year period. The NIST taxonomies and the original functional basis were intended to support manual and software based applications of functional modeling methods. After joining forces with NIST, the research team reconciled their existing models and language to create a standard functional basis and obtained funding from NSF under NSF:DMI-9988817 to create an online repository of functional models. Today, this repository consists of 184 products and 6,906 artifacts and is available through the Design Engineering Lab website at Oregon State University. The functional modeling research has continued to be fundamental in a number of research initiatives since the completion of the original joint research projects, and has been applied with numerous industrial partners over a ten to fifteen year period (Stone et al. 2000; Stone & Chakrabarti 2005; Linsey et al. 2008; Chakrabarti, et al. 2011; Chan et al. 2011; Fu et al. 2011; 2012; 2013; Braha et al. 2013).3.2.4 Product Innovation and New Companies

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In this section, we describe successful cases of guidelines #4 and #5 for incubating companies and designing within research. At Tecnológico de Monterrey (Querétaro, Mexico) one of the authors led the school of industrial design from 2007 to 2011. In those five years, more than a dozen design studios and companies were created by graduates of this school, such as: Mooid (mooid.mx), Dandelion (dandelionlab.com), Moxo (moxo.com.mx), Arroz con Leche (arrozconlechemama.com), Xarzamora (xarzamora.com), IbarraChacho (ibarracacho.com), Olab (o-lab.com.mx), GaloBertin (galobertin.mx), CGN (casagutierreznajera.com), Dix (dix.mx), Somos Diseño (somosdiseno.com), Urnas Sacbe (urnassacbe.com), Fabrica Ecologica (www.fabricaecologica.com), Pata de Perro (patadeperroestudio.mx), Art68 (art68.com.mx), etc. In three specific cases, graduate research theses constituted the basis for incubating or accelerating such companies, namely: Ecopilia (ecopilia.com.mx), Materializadora (canastasdemimbre.com), and Relement (relement.mx).

In the case of Ecopilia, Prof. Victor Martinez and his graduate student Gabriela Gutierrez developed an innovative composite material and a low volume manufacturing process with the sustainability principle of cradle-to-cradle. The name of the company derives from the words *oikos* (home in Greek) and *copilia* (return in Nahuatl), i.e., "take back home (nature) all we have taken from it." The research project produced a patent for the composite material based on corn and paper fibers, which is biodegradable, compostable and recyclable[1]. The process itself is carbon neutral, using custom solar ovens and processing equipment. The material was subsequently applied to the development of new products substituting materials of high embodied energy such as glass fiber and MDF (Gutierrez Pliego 2009). Ecopilia entered the local business incubator in 2009 and continues to grow today.

Juan José Navarro had previously co-initiated Materializadora as a spin-off of a student club in the school of industrial design. The company set to develop innovative products by transforming low-value handcrafts, such as nondescript baskets made of woven natural fibres. Their business plan followed a 'fair trade' model where local artisans receive training in design techniques and manufacturing processes and are compensated fairly for their work. The first products offered by Materializadora were original designs by peer undergraduate students. In 2010, as a graduate student in the Master of Design, Manufacturing and Innovation, Juan José worked under the supervision of one of the authors in the development of new rapid modelling and prototyping equipment based on wire bending techniques. This cross-disciplinary project was conducted by industrial designers and mechatronic engineers, resulting in three Masters' theses. Firstly, the impact of using wire for model-making during idea generation was modelled as compared to other conventional materials used by industrial designers in the early stages of

[1] http://www.itesm.edu/wps/wcm/connect/snc/portal+informativo/news/patentbioixim4mar13

model-making and prototyping including cardboard and clay (Juarez 2009). This was followed by the design of rapid 3D modelling techniques with formative manufacturing processes (Cardenas et al. 2011). Lastly, the wire bending machine was built and its impact on idea generation evaluated experimentally, including in participatory design processes by cross-disciplinary teams (Navarro 2010). From this work, new product families were added to the company's portfolio, which today offer 34 products in six product lines with eight choices of materials.

Estefania Juarez and Alba Sanchez co-founded QuieroAire in 2009, renaming it Relement in 2011. This start-up was initiated as a result of an elective design research and innovation graduate seminar created and taught by one of the authors. In this seminar, teams of engineers and designers worked with local companies in order to identify latent problems and opportunities for design-driven innovations. Based on the author's studies of creativity and innovation processes (Sosa 2005, Sosa and Gero 2008, Sosa et al. 2009), students applied a situational approach to identify potential for radical improvements, where the target was a change of one order of magnitude – so as to go beyond optimization or continual improvements. Creativity and innovation were managed in three complementary dimensions in these projects: the creative individual (the team of students and change agents identified within and beyond the company), the field (the departments and divisions involved in the design and engineering of the products and processes being analyzed) and the domain (the established practices, norms and the general culture of the company).

By applying the principles and techniques covered in the seminar in real settings in local companies, five teams identified a large number of factors, barriers and leverage points in proposed innovation strategies that ranged from original revenue models for scrap materials to new applications of advanced technologies, and, in the case of Relement's founders, to new opportunities given by the industry practices related to the use, management and disposal of refrigerants and air-conditioning equipment. The seminar concluded with teams receiving feedback from the partner companies on the originality, feasibility and value of projects. In this particular case, the company failed to identify the value of these ideas arguing that although interesting, they were incompatible with the established growth strategies. However, the students received very positive feedback from professionals, academics and government officers who encouraged them to enroll in the local business incubator; it was initially named QuieroAire. A few months later, the project secured two separate grants, one from the local government and one from a private bank. Since then, Relement has refined the original definition, vision and mission, and today it offers sustainable solutions to reduce the footprint of air-conditioning and provides consultancy on environmental management of greenhouse gases and lifecycle analysis.

The three cases presented here had quite dissimilar starting points and motivations. In fact, none of them were actually initiated with the explicit aim of incubating a company. The fact that more than a dozen design-related companies were created during this time, suggests that an entrepreneurial culture was being shaped. But the cases of Ecopilia, Materializadora, and to a greater extent, Relement illustrate that design research can easily find valuable applications in practice, whether by commercializing a patentable material, introducing novel model-making and prototyping techniques to accelerate the growth of a company, or pursuing innovation projects identified and framed with novel design approaches. It is noteworthy that these three companies have survived the always problematic first years of a new venture, and they continue to grow after four years. It is also of interest that these three companies have very strong foundations in sustainability, a core value of the school of design at the time. Ecopilia was a research project initiated by a faculty member and was developed systematically as a graduate thesis. Materializadora was an existing company that incorporated knowledge and techniques from a chain of graduate theses, including that of one of its founders. Relement is a remarkable case of an innovative company originated as a student project with clear potential that was overseen by the original partner, but strongly supported by knowledgeable industry experts.

3.2.5 Design courses and experiences

In this final section, we consider cases under guideline #13 for immersing students at all levels of design-based learning. As the head of the school of industrial design at Tecnológico de Monterrey (Querétaro, Mexico) from 2007 to 2011, one of the authors oversaw initiatives leading to the establishment of close partnerships between companies and design studio courses across the undergraduate curriculum. These partners ranged from MNCs to SMEs, as well as government and non-governmental organizations: Campbell's México, Hafele Mexico, Creapack, Guaily, Imbera Cooling, Fundación Bertha O. De Osete, Mexico Tierra de Amaranto, Centro para Adolescentes San Miguel de Allende, Mars Mexico, etc. In these cases, students from semesters 1 to 8 developed new product designs coached by faculty and based on briefs provided by the client. Capstone projects in particular led to innovative designs that were frequently incorporated into the company's product strategy. In two particular cases, design research had a clear impact in practice: Mabe Mexico (www.mabe.cc) and Delegacion Miguel Hidalgo (miguelhidalgo.gob.mx).

The capstone projects with Mabe Mexico in 2008 and 2009 had two main themes: next-generation refrigerators and washing machines. This course was led by the author, Victor Martinez and Joel Gaona. The most promising product designs developed during the semester were selected by the design director of the company, and the group of students received a one-year internship at the R&D department of the company to continue the new product development (NPD) process including detail design, user testing and feasibility studies. Several solutions presented to Mabe identified clear opportunities for design and technology innovations in response to unique social and market conditions in Mexico and other Latin American countries. The university-industry link here defies the conventional transfer of academic research into design practice: highly creative product designs were produced by students at the conclusion of their studies, and these ideas served as inputs to the R&D process of the company, one of the main private centers of research in the country (Bonaglia et al. 2007).

The project with Delegación Miguel Hidalgo in 2008 was motivated by the increasing systemic problems associated with solid waste disposal in one of the busiest areas of Mexico City. With more than 20 million inhabitants and 650,000 tons of daily waste that ends up in landfills, the team led by Victor Martinez and Pablo Herrera applied design tools and techniques developed based on sustainability and systems thinking. The outcomes of this project included innovations in waste management equipment, public policy and business strategies ranging from food packaging to local recycling and biogas plants. The *Waste Recovering System* project became an Award Finalist at the Index Awards of 2009 (designtoimprovelife.dk). This design project validated a cross-disciplinary study of practices across the schools of business, engineering and industrial design (Sosa et al. 2010). Regarding systemic reasoning, our studies had suggested that the distinctions between disciplinary and multi-disciplinary teamwork are weaker than what is usually expected. The fact that this team of last-year product designers produced such remarkable results applying techniques of high-order systemic thinking, further confirms our initial research findings.

3.3 Discussion

The overarching themes of Sections 2, 3.1, and 3.2 debunk perceptions commonly held by industry professionals and academics alike. Although many believe that few academics practice design and engage industry, our studies indicates that many design researchers have significant design experience and intellectual property. Although many believe that design research is carried out in a silo, separate from business and industrial R&D, it seems that more than a third of design research, as reported in academic research journals, not periodicals from practice, contributes to business and industrial R&D. Furthermore, the effect of educating undergraduate and graduate students in design science is severely underappreciated, as shown by many of the IDRP examples. From considering these successful interactions, an extensive set of guidelines and mechanisms materializes, as shown in Table 2, for impacting practice. Given the amount of evidence we have presented and the limitations of these sources, we argue that impact upon of design research on practice is quite extensive and even greater than can be discerned from the literature.

First, let us consider the relationship between archival publications and practicing designers. Only one of the five top journals in design research, the Journal of Research in Engineering Design (RED), specifies industry professionals as the audience for their publications. In general, archival publications are not written for practicing designers, who have little background information and limited time to read 10-page or longer articles. Outcomes for specific applications are often implicit, ancillary, formed through relationships, developed through hiring and pro-

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fessional development, or fostered through method transfer, design research products on the market, or actual projects that directly affect a business' bottom line. Research articles, on the other hand, focus on the design research theory and development. Design research is published with the intention of advancing knowledge through revisiting the literature, and publishing research methods and results. Industrial professionals are not, nor should they be, the intended audience for academic journals.

Given the time required to produce journal-quality publications, the fact that 9% of design research published in the past two years was authored by a non-academic professionals is astounding. It is encouraging that non-academic professionals have the time and interest to read, let alone write, design research publications. More appropriate mechanisms for creating accessible research in the language of practice are found under the guidelines of branding and disseminating (9) and engaging practitioners in professional development (12). For example, dynamic and engaging videos, periodicals, blogs, and continuing educational programs, provide the essence of actionable knowledge without the verbose discourse of research questions and procedure.

The estimate, from our analysis, that one third of design research involves knowledge transfer might underestimate the true impact of design research on practice. A severe limitation of relying upon archival journals is that true impacts of design research on practice are often un-publishable. Most obviously, IP issues and proprietary information present just one set of conditions preventing publication of industry and research collaboration. Additionally, many interactions between industry and research occur outside of the publishable research, through consulting, workshops, and in the trenches of design. If we consider the IDRP case with Prince Automotive, no publication related the fact that the graduate student involved was hired by Prince to train very senior and experienced design engineers in the techniques he developed. In the case of the functional basis development, contributions to Ford through workshops, product development, automotive and platform design, and partnership and contributions to DTM through design modeling and system evolution were omitted from the journal articles. Such outcomes of partnerships are, typically, left to brief acknowledgements, where the primary audience seeks to push the research frontier through the rigorous academic process.

Secondly, our definition of practice includes government agencies, and non-academic research labs, but one could impose an alternative, conservative definition of practice that is restricted to businesses and manufacturers of commercial products. If we revisit the findings from the previous sections under this definition, the authors' examples would omit interactions with NIST to create standards for practice and application. As evident in the guidelines, standards are an important aspect of practice. If we remove government and other research agencies, such as the US Army Research Institute, US Army Corps of Engineers, NASA, and the Office of Naval Research, from the sample of journal articles evidencing knowledge transfer, the percentage of papers with knowledge transfer reduces from 39% to 33%. Type 3 knowledge transfer reduces from 20% to 14%. The changes are relatively small and within the margins of error because not all papers reference government agencies alone. Many include consultation, authorship or funding with other commercial business partners who design and manufacture products for the government, such as Bechtel or Lockheed. It is difficult to separate defense funding, research labs, and agencies like NASA or NIST from commercial companies. These agencies are strongly linked, if not responsible for technology readiness and industry practice.

Thirdly, the focus on archival journals and academic venues limits our perspective to the side of academia. Optimistically, many interactions exist outside of these venues. For example, students, beyond the classroom and research lab, bring knowledge from their coursework to their new job and change practice either immediately or over time. Pessimistically, the impact of the research could be overstated. Perhaps funding from a source was allocated to a side project unessential to the funding agency's interests. Additionally, papers that report high industry impact might only enact short term results and not long-term change in practice. Additionally, research may never be read by the funding agencies. Such situations are possible, but not in keeping with the authors' experience. In the authors' examples of IDRP, successful interactions often lead to long-term partnerships and change.

Writing from an academic perspective leaves many industry-side mechanisms and guidelines un-considered. A separate and complementary set of guidelines can, hopefully, be derived from the other chapters within this anthology. Similarly, we envision that the guidelines in Table 2 could be re-stated from an industry perspective, or as industry undertaking the actions. For example, guideline #11 for housing practicing professionals on campus could be translated as housing academic researchers at corporate offices through sabbaticals and internships or advisory boards.

With the perception that design research is quite successful in impacting practice, the conversation changes focus and we can consider opportunities for capitalizing on the existing strengths of design research in academia and existing mechanisms for bringing design research to practice. The power of the guidelines presented in this chapter is that they are successful and proven strategies. The associated mechanisms are actionable, not only individually, but in combination, creating more opportunities for engaging practice in design research than can be reasonably enacted. These guidelines span from the initiatives of individual researchers to departmental and campus-level initiatives. The examples provided in this chapter of IDRP are but a small sample of the authors' experiences, and the reader is encouraged to refer to this set of guidelines when reading the other chapters within this anthology.

Although many of the guidelines and much of this chapter focus on published studies, consultations, and workshops, the most powerful mechanisms for transferring research to practice engage students. Education of future designers and industry leaders is one of the most important tools for bringing research to practice. Design thinking is a culture and approach to problem solving that must be learned.

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University curricula are important mechanisms for transferring ownership of the knowledge created by design research. All research outcomes of the IDRP examples within this chapter have been integrated into university level curricula and practiced by thousands of engineering students. If one author is responsible for the education of over 4,000 professionals, then a community of design researchers, as educators, has undeniably significant impact.

4. Conclusions and Contributions

Conversations of the important linkage of design research and design practice are natural and important. Perceptions of the degree to which design research has impacted or made a difference in design practice are equally important. However, this chapter seeks to change, or at least call into question, stereotypical conversations and perceptions of the relationship and measures to which design research has significantly affected the practice of design.

Basic research in design should be highly valued, savored, and encouraged. As a scholarly field with the objective of contributing intellectual merit and long-lasting knowledge, a design research community cannot exist without basic research. Likewise, our community must have strong ties to practice and ultimately impact practice through the transfer of processes, methods, tools, and technology that lead to innovations for societal need and the development of the next generation of design leaders for an innovation economy.

The general studies presented in this chapter are encouraging. Whereas some may believe that very little impact results from design research, an analysis of the literature and a survey of a segment of design researchers show that design practice is embraced and pursued. These findings should be the starting point and basis for our conversations and perceptions of understanding the impact of design research on practice.

Building upon these foundations we have presented in this paper a collective set of guidelines and platforms for engaging design practice from design research entities. These guidelines and platforms are discussed more fully through a set of cases where design research has been successfully transferred to industry or related organizations. Guidelines and platforms of this type will enrich the design research community's pursuit of growing and evolving design as a science and the practice of design, collaboratively with design practitioners across many fields, institutions and national borders.

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