Exploring the Scientific Impact of Information Systems Design Science Research: A Scientometric Study

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Abstract

Design science is a fundamental research stream that contends its position in the information systems discipline. While ongoing debates address the relative importance of design science contributions in the information systems community, insights into the scientific impact of design science research (DSR) are missing and this lack of understanding arguably poses challenges to an informed discourse. To identify the most influential papers and those factors that explain their scientific impact, this paper presents an exploratory study of the scientific impact of DSR papers published in the AIS Senior Scholars' Basket of Journals. We uncover the current DSR landscape by taking stock of influential papers and theories and develop a model to explain the scientific impact of DSR papers. Our findings show that scientific impact is significantly explained by theorization and novelty. We discuss how the implications of our work can be projected on the overarching discourse on DSR.

Keywords: Design science research, scientometric, impact of research methods

Introduction

Information systems design science research (DSR)[1] is characterized by the underlying pursuit of dual objectives (Gregor and Hevner 2013; March and Smith 1995; Simon 1969, p. 3): (1) Developing useful artifacts that can be deployed in practice, and (2) producing generalizable knowledge contributions to a cumulative body of design knowledge. Beyond these dual objectives that are inherent in every DSR project, researchers are confronted with a variety of stakeholders and expectations. For example, practitioners might appreciate novel insights, researchers might value a strong connection to extant theoretical work, and students might appreciate illustrative and accessible examples. Hence, authors are challenged to advance the impact of their design science papers by communicating, positioning, and possibly repackaging their research, for example by publishing condensed versions of their research in ways that are more accessible and actionable for practitioners. First and foremost, however, this requires a better understanding of the impact of design science, an issue that is persistent in the ongoing discourse

[1] While the paper might be relevant in the general context of design science, we primarily focus on DSR in information systems.

(Arnott and Pervan 2012; Goes 2013; Gregor and Hevner 2013; Nunamaker et al. 2017; Prat et al. 2015; Rai 2017). Gregor and Hevner (2013) prominently raise the question of how to position and present design science for maximum impact, considering impacts on the development and use of information systems, on future DSR projects, on the information systems community, and on practitioner knowledge areas. With these different types of impact in mind, our study focuses on scientific impact, which is commonly measured in terms of citations (Grover et al. 2013; Judge et al. 2007). Although other types of impact might be deemed equally important, scientific impact is arguably relevant for the career of design science researchers as many committees use it for hiring, tenure, and promotion decisions. It can also be considered indicative of knowledge diffusion into research and practice.

We argue that there is a lack of empirical insights into the landscape of influential DSR papers. In contrast to methodological and philosophical DS papers, this part of the DSR body of knowledge is not fully transparent. In a nutshell, the need to take stock of influential DSR papers and theoretical contributions is evident. Further, or in the words of Gregor and Hevner (2013), we address the question of “What positions them for maximum scientific impact?”. Understanding what actually distinguishes high-impact design science arguably requires an adequate methodological approach to disentangle aspects of the design paper, such as its theoretical contribution, and the effects of author and journal reputation. To the best of our knowledge, there is no comprehensive study of the impact of DSR papers that is published in premier information systems journals. We therefore raise the following research question:

> *What are the most influential DSR papers in information systems and which factors explain their scientific impact?*

To address this question, we conducted a scientometric study of 115 papers published in the AIS Senior Scholars' Basket of Journals between 2004 and 2014. Complementing existing scientometric research on design science, our study is the first to consider a large set of journal papers. The main contributions of this paper are to identify the most influential DSR papers, and to analyze what distinguishes DSR papers that are cited frequently. We thereby provide valuable insights into the impact and diffusion of design knowledge in information systems. These insights are valuable for (prospective) authors of design science papers, for committees evaluating design science research, and for the information systems discipline to appreciate the differences in scientific impact that can be expected from design science papers.

In the following, we report results from an extensive scientometric study of the scientific impact of DSR. Based on a review of extant work on design science and scientometric studies of citing behavior (Section 2), we develop a model that explains the scientific impact of DSR papers based on novelty and theorization (Section 3). We evaluate these factors empirically using a generalized linear regression model and show that they are robust predictors of scientific impact (Sections 4 and 5). Before concluding the paper, we discuss the landscape of prominent design theories and papers as well as possible avenues for further research (Section 6).

Background

Scientific impact is one aspect that is analyzed by scientometric studies, which use quantitative methods to analyze the structure (Nahapiet and Ghoshal 1998; Xu and Chau 2006) and evolution (Straub 2006) of scientific disciplines. A major research stream focuses on studying the scientific impact of knowledge contributions (Mingers and Xu 2010; Stremersch et al. 2007), how they diffuse through the literature (Grover et al. 2013), and how they constitute the fundamental building blocks of the academic discourse (Hansen et al. 2006). In scientometric works covering the whole information systems discipline, design science research has been noted as an important research stream (Sidorova et al. 2008; Xu and Chau 2006). In order to account for and identify genre-specific impact, scientometric studies have tailored their models to specific types of papers (e.g., Tams and Grover 2010 and Wagner et al. 2016). Regarding scientometric research that focuses on design science exclusively, there are a few papers that primarily focus on design science published at the DESRIST and BISE conferences. While initial evidence indicates that scientific impact varies between different artifact types, evaluation methods, and domain (Samuel-Ojo et al. 2010), the primary focus of these studies has been devoted to identifying clusters of design science papers (Akoka et al. 2016), and conducting co-citation analyses to determine papers that are used frequently by design science researchers (Akoka et al. 2016; Fischer 2011; Piirainen et al. 2010). In summary, these works provide lists of the most prominent design science papers (such as Hevner et al.

2004, March and Smith 1995, Simon 1969 and Walls et al. 1992), but at the same time, they reveal that these lists are dominated by methodological papers and that there are astonishingly few influential papers that focus on developing an artifact. This suggests that the question of whether a distinct design science body of knowledge has emerged cannot yet be answered with a unanimous yes.

Before we analyze influential DSR papers and factors that position them for maximum scientific impact (in the following sections), we provide an overview of design science research in information systems and theories that have been advanced to explain citing behavior.

Design Science Research in Information Systems

The design of information systems is a persistent theme in information systems research and design science has gained recognition as a fundamental cornerstone of the information systems discipline. To position their research, design science researchers frequently refer to Simon (1969), who distinguishes the natural sciences from the sciences of the artificial, which are grounded in the logic of design. While the former is concerned with "how things are", the latter "is concerned with how things ought to be, with devising artifacts to attain goals" (Simon 1969, p. 114). Although providing a useful and clear distinction, the work of Simon has prompted debates on how both types of research relate to each other. In one of the classics on design science in information systems, March and Smith (1995) have cautioned that disagreements between proponents of both paradigms and a corresponding dichotomy of natural vs. design science might be harmful to the information systems discipline. This pursuit of an integrated body of knowledge can be recognized in works of theorists and methodologists (e.g., Iivari 2007 and Kuechler and Vaishnavi 2008), who envision a research tradition in which both descriptive research (natural science) and prescriptive research (design science) mutually inform each other.

Consistent with the literature (Vaishnavi and Kuechler 2004), Venable and Baskerville define *design science research* as "Research that invents a new purposeful artifact to address a generalized type of problem and evaluates its utility for solving problems of that type" (2012, p. 142). In information systems, design science research focuses on building a variety of socio-technical artifacts (Bostrom and Heinen 1977a, 1977b; Gregor and Hevner 2013; Niederman and March 2012), which are commonly distinguished according to the framework of March and Smith (1995). This framework of design science research outputs, which contains constructs, methods, and models, has been modified and extended in extant literature (Alturki et al. 2011; Drechsler and Dörr 2014; Dwivedi et al. 2014; Offermann et al. 2010). Notably, the concluding call of March and Smith (1995, p. 263) for "generalizations or theories explaining about why and how (or even if) any of these artifacts work" points to design theory, which has been discussed widely and which is also recognized as a distinct contribution of design science research.

One aspect that has been discussed widely relates to the type of novelty that should be expected from a DSR paper, encompassing the question of what distinguishes routine, professional, commercial, or industrial design from design science. The importance of this distinction is reflected in several prominent design science papers (e.g., Baskerville 2008; Gregor and Hevner 2013). In his advice to doctoral students, Davis (2005) emphasizes that routine, or industry design is not suitable for a research paper, because it rarely makes "a contribution to knowledge other than actually doing something that everyone knows can be done and at least conceptually how to do it" (p.18). Similarly, Niederman and March (2012, p. 1:11) emphasize three conditions, either of which qualifies a design-oriented paper as design science: (1) Demonstrating that building an artifact is technically feasible despite doubts about its feasibility, (2) developing an "innovative solution to an important problem", or (3) substantially improving our "understanding of the problem space for an important class of problems". Types of novelty are also reflected in the framework of Gregor and Hevner (2013), which distinguishes DSR based on the novelty of the solutions proposed and the novelty of the problem addressed[2]. While routine design applies known solutions to known problems, improvement refers to the development of novel solutions to known problems, exaptation describes the transfer of known solutions to new problems, and invention requires novelty of both the problem and the solution (cf. Figure 1).

[2] Gregor and Hevner (2013) refer to the constituent dimensions of the framework as *solution domain maturity* and *application domain maturity*. We prefer to frame it as novelty because maturity might also be associated with generalizability or design theory.

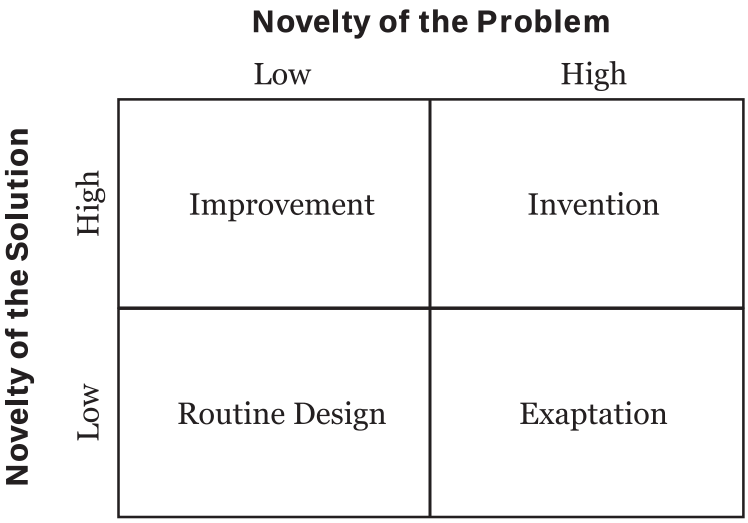


Figure 1. Types of Novelty of DSR Papers (Based on Gregor and Hevner 2013)

A second fundamental aspect of DSR is design theory as a more generalizable knowledge contribution that conceptualizes mechanisms or principles that enable artifacts to fulfill their purpose. In contrast to situated knowledge gained by specific instantiations or prototypes, the value of design theory is constituted by its (relative) independence of idiosyncratic aspects of a particular context and by its applicability to a general class of problems (Baskerville et al. 2015). While the paradigmatic foundations for design theory in information systems have been discussed early on (Weber 1987), the four essential components of an information systems design theory, which have been proposed by Walls et al. (1992), have been recognized widely but adopted slowly (Walls et al. 2004). Specifically, a design theory comprises meta-requirements (describing a class of goals), meta-design (describing a class of artifacts that are intended to meet the meta-requirements), kernel theories (natural or social science theories that inform the design requirements), and testable hypotheses (for verifying whether the meta-design is effective) (Walls et al. 1992, pp. 42–43). As such, design theory has been recognized as one of the fundamental types of theories in information systems (Gregor 2006). It has prominently raised the interest of theorists who have addressed the anatomy of design theory (Gregor and Jones 2007), the question of how design theory should be developed (Gregor 2009), how the explanatory value of design theory can be made transparent (Baskerville and Pries-Heje 2010), and how design theory might interact with kernel theories (Kuechler and Vaishnavi 2008). Recent papers (Alturki 2016; Lee et al. 2011; Lukyanenko and Parsons 2013; Niehaves et al. 2012; Venable 2013; Widmeyer 2012) indicate that the role of theory continues to be a significant theme in the discourse on design science.

Scientometric Theories of Citing Behavior

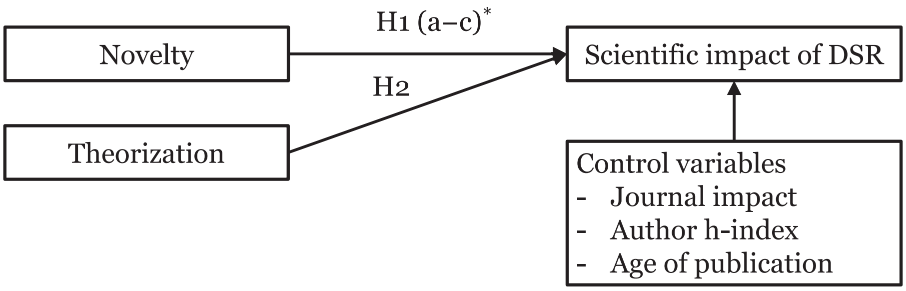
The two established theories that explain citing behavior are the normative theory and the social constructivist theory (Hassan and Loebbecke 2010). The normative theory, mainly advanced by Merton (1973), defines a citation as an acknowledgement of the intellectual use of other authors' work. In this view, citations represent an intellectual or cognitive influence of the cited paper on the citing paper. This normative perspective has motivated many citation analyses, leading to the development of scientific impact measures which, consequently, all rely on the validity of the normative theory of citing behavior (Thornley et al. 2015).

The competing social constructivist view (Gilbert 1977) contends that authors cite in order to persuade their readers. Hence, citing is seen as a rhetorical system through which researchers try to convince the scientific community of the value and relevance of their own work. This social and economic conditioning of the audience can be based upon the impact of journals, the prestige of authors, self-interest, or a target audience (Gilbert 1977). In essence, this theory posits that citations can also be socially constructed to support the authors' own arguments instead of acknowledging the intellectual contribution of the cited work. The social constructivist theory clearly questions the use of citation counts as a measure for quality, or influence of papers in case the main proportion of the citations does not rely on the intellectual content of the cited work (Knorr-Cetina 2013).

Many studies have been conducted to empirically test the validity of both theories (Bornmann and Daniel 2008). Citation network approaches provided evidence for a significant positive correlation between the number of citations and paper quality, providing support for a normative view of citing behavior (Baldi 1998; Stewart 1983). Interview and questionnaire based studies, asking the authors what their motivations were to cite certain papers, also conclude that Merton's normative theory better explains their results (Shadish et al. 1995; Thornley et al. 2015).

Model

As suggested in the previous section, we argue that novelty and theorization, with design theory representing the highest level of theorization, are factors that influence researchers' decisions to cite a DSR paper. We use these factors to develop a research model that explains the scientific impact of DSR papers (Figure 2). They are consistent with the normative theory of citing behavior while control variables may reflect constructivist citing behavior[3]. Thereby, our model accounts for complementary effects of the normative and constructivist theory of citing behavior as they are discussed in the literature.



*Separate hypotheses are formulated to compare the effects of different levels of novelty (routine design, exaptation, invention) to the reference group (improvement).

Figure 2. Research Model

Scientific Impact

A general assumption of scientometric studies, which builds on the normative theory of citing behavior, is that citation counts are an appropriate measure of scientific impact (Grover et al. 2013; Starbuck 2005). Sometimes, citations are even used as an indicator for quality (Acuna et al. 2012; Garfield 2006), and they are frequently used for promotion, tenure, and funding decisions (Bertsimas et al. 2013; Dennis et al. 2006; Lewis et al. 2007). Critical reflection has led to a scientometric stream aiming at going beyond pure citation counts (Hassan and Loebbecke 2010) by exploring the functions and motivations behind citations in order to achieve sufficient depth in our "understanding of the structure of scientific research" (Moravcsik and Murugesan 1975, p. 92). Notwithstanding the critique that citation counts might be subject to certain biases (Leydesdorff 1987; MacRoberts and MacRoberts 1989), they are frequently used as measures for scientific impact (Hassan and Loebbecke 2010) or scholarly influence (Straub 2009). Furthermore, citation counts have been shown to correlate with paper quality (Baldi 1998; Stewart 1983). Deemed as one of the best measures there is for evaluating scientific quality, the importance of citation counts for authors and the research community is manifest (Garfield and Merton 1979).

[3] To clearly distinguish the degree to which the factors stimulate normative or constructivist citation behavior, it would be necessary to analyze exactly the way citing papers use a DSR paper.

Hypothesis Development

Consistent with the normative theory of citing behavior (Merton 1973), our model predominantly draws on substantial qualities of a paper to explain scientific impact while simultaneously controlling for more constructivist aspects (Gilbert 1977) such as author reputation and journal visibility. As normative citing behavior is associated with attributing intellectual and cognitive influences, corresponding factors commonly include a paper's generality (Ellison 2002), its agreement with the literature (Uzzi et al. 2013), the rigor of its research methodology (Judge et al. 2007), and novelty or originality of the contribution (Grover et al. 2013). Considering the broad range of different types of research, such as literature reviews, case studies, and opinion papers, it is evident that these paper types cannot be compared directly and that factors specific to the quality of DSR papers need to be developed[4]. To tailor a model that is appropriate for the specific characteristics of DSR, we draw on the DS literature that discusses various qualities and desirable properties of DSR papers. Overall, we contend that the two factors that were introduced in the background section intellectually or cognitively influence other researchers and affect scientific impact: (1) The type of novelty of the research contribution, and (2) the level of theorization. We discuss anticipated effects of each factor and subsequently derive corresponding hypotheses.

Novelty, or innovativeness, of a paper has been shown to correlate significantly with scientific impact (Grover et al. 2013; Judge et al. 2007; Stremersch et al. 2007; Uzzi et al. 2013). One explanation is that, for conventional papers, there are plenty of alternative works that could be cited, while novel papers make unique knowledge contributions that provide a foundation for streams of subsequent research (Tams and Grover 2010). Put differently, novel papers have the distinct advantage of being the first to explore new questions or advance new approaches. In DSR, novelty can relate to the solution or the problem (Gregor and Hevner 2013). While addressing known problems with known solutions would be a rare case of routine design, DSR papers improve solutions to known problems or demonstrate how existing solutions can be applied to new problems (exaptation); addressing new problems with completely new solutions is highly innovative but also rare in DSR (Gregor and Hevner 2013). It still needs to be understood, though, to what extent the effects of novel ideas apply in the DSR domain and how strong they actually are. Hence, we explore hypotheses for the types of novelty relative to improvement, which is frequently offered by DSR papers (Gregor and Hevner 2013):

Hypothesis 1a Scientific impact is lower for DSR papers focusing on routine design (applying known solutions to known problems).

Hypothesis 1b Scientific impact is higher for DSR papers focusing on exaptation (applying known solutions to new problems).

Hypothesis 1c Scientific impact is higher for DSR papers focusing on invention (developing new solutions for new problems).

Scientometric research has shown that more general research contributions are cited by a broader audience (Siering et al. 2014; Tams and Grover 2010). In this vein, the DSR contributions can span different levels of theorization and provide insights that might be more specific to one particular problem context, or they might be of a more general nature and applicable to a variety of problems and contexts. This distinction is akin with Baskerville's discussion of idiographic and nomothetic knowledge contributions of DSR papers (Baskerville et al. 2015). Specifically, DSR contributions of lower theorization are prototypes and instantiations. Constructs, models, and methods (March and Smith 1995) represent nascent theorization while high theorization is generally achieved with information systems design theories (Walls et al. 1992), and theoretical contributions to information systems design that identify and explain underlying mechanism of a design. Methodologists have argued that generalizability of DSR contributions should be backed by appropriately tying these mechanisms to existing bodies of knowledge (Dwivedi et al. 2014; Gregor and Hevner 2013; Kuechler and Vaishnavi 2008). As design-oriented contributions often address phenomena and contexts which have been analyzed by *natural science* research, they should be leveraged in corresponding research and kernel theories (Gregor and Hevner 2013). These recommendations also align with what Hevner (2007, p. 87) envisions as the essential

[4] The need for adapting scientometric models to specific types of papers is reflected by the fact that scientometric studies tend to focus on different genres have been published (e.g., Tams and Grover 2010).

contribution of the *rigor cycle*, which "provides grounding theories (...) from the foundations knowledge base into the research". Drawing on established works, as one aspect of theoretical DSR contributions, signals to other researchers that the DSR paper is the solid foundation that they can build on. Similarly, extant scientometric research has found that influential papers tend to demonstrate familiarity with existing research by drawing on established research contributions (Uzzi et al. 2013), and a strong connection to the existing knowledge base has been suspected to affect scientific impact of DSR papers (Gaß et al. 2012). In summary, persistent calls for DSR at high levels of theorization, including design theory (Arnott and Pervan 2012; Gregor and Hevner 2013; Walls et al. 2004), prompt us to explore the following hypothesis:

Hypothesis 2 Scientific impact is higher if DSR contributions are theoretical.

Control Variables

Beyond the age of publication, which predicts scientific impact (Grover et al. 2013; Mingers 2008), author impact has consistently been found to significantly affect the impact of papers (Judge et al. 2007; Peters and Raan 1994). Due to the many ways in which an author may impact an academic field, measuring author impact is a complex task. Among several instruments, which have been developed to measure the scholarly impact of an author's publication record, the Hirsch family of indices is the most prominent one (Hirsch 2005; Truex et al. 2009). A meta-analysis by Bornmann et al. (2011), which analyzes the validity of the h-index as a measure for author impact, describes two dimensions of author productivity: (1) The quantity (as measured by publication counts) and (2) the impact of an author's publication volume (as measured by citation counts). The h-index is a measure, which combines both productivity and impact of an author.

The journal in which a paper is published has been found to be the single most important factor driving citations to a paper (Judge et al. 2007; Mingers and Xu 2010; Peters and Raan 1994). Multiple factors related to the publication outlet have been shown to significantly influence the number of citations a paper receives, such as reputation, visibility, accessibility, or a paper's position within a journal issue (Bornmann and Daniel 2008; Dalen and Henkens 2001; Judge et al. 2007). As many of these factors are interrelated, scientometric studies commonly use the journal impact factor as a proxy. Originally proposed by Garfield (1964), the impact factor has attracted the attention of the research community as well as of governments, administrations, funding and research councils (May 1997; Seglen 1994). Although Garfield (2006), the creator of the social science citation index (SSCI), concedes that the journal impact factor might not be a perfect measure, he concludes that the impact factor is well established and that a better metric still has to be found.

Methodology

Sample

To analyze factors that explain scientific impact of DSR, we focus on high-quality DSR papers published in premier information systems journals as our unit of analysis. Specifically, the scope of our study covers DSR papers published between April 2004 and March 2014 in journals included in the AIS Senior Scholars' Basket of Journals (AIS 2011). DSR papers were identified by Prat et al. (2015), who conducted a table of contents scan, a keyword search, and an inclusion coding procedure. We discuss possible extensions of the scope in the penultimate section. As a refinement of the set of 121 DSR papers identified by Prat et al. (2015), we excluded design science papers focusing on methodology (Peffers et al. 2007), theory (Gregor and Jones 2007; Kuechler and Vaishnavi 2012), evaluation guidelines of design science (Burton-Jones et al. 2009), or on classification methods for researchers (Nickerson et al. 2013; Parsons and Wand 2013). The rationale for excluding these papers is that they target a much broader audience, introducing problems of heteroscedasticity into our analysis. This means our study focuses on DSR papers that contribute to building or evaluating artifacts not primarily addressing researchers, a notion consistent with the literature on design science (e.g., Fischer 2011, March and Smith 1995). The exclusion coding was conducted by two of the authors and resulted in a final set of 115 DSR papers.

Measures

To operationalize our model, we refer to established references from the literature (Table 1). Scientific impact was measured in terms of citations as commonly suggested in the literature (Grover et al. 2013; Judge et al. 2007; Tams and Grover 2010); citation data was extracted from Google Scholar as of April 20th, 2017.

Table 1. Factors of the Research Model

Factor	Measurement	References
Dependent Variable		
Scientific impact	Total number of citations from Google Scholar, as of April 20th, 2017	Merton (1973) Garfield and Merton (1979)
Main Variables		
Novelty	Routine design, improvement, exaptation, and invention	Gregor and Hevner (2013) Grover et al. (2013)
Theorization	Highest level of theorization: 1. Not included (instantiation) 2. Nascent (construct, model, or method) 3. Partial (design theory containing some components described by Walls et al. (1992)) 4. Complete (design theory containing all components described by Walls et al. (1992))	Gregor and Hevner (2013) March and Smith (1995) Walls et al. (1992)
Control Variables		
Journal impact factor	Journal impact factor provided by Thomson Reuters	Judge et al. (2007) Mingers and Xu (2010)
h-index of the first author	An author with h-index *i* has published *i* other papers (at time of publication of the DSR paper) that have at least *i* citations [a] (citation data was provided by Scopus)	Hirsch (2005) Truex et al. (2009)
Age of publication	Time since publication	Grover et al. (2013) Mingers and Xu (2010)
Notes. [a] As Scopus only provides the most recent h-indices, we used author publication lists to recalculate h-indices for the point in time when the DSR paper was published, i.e., we corrected for the number of publications, but not for citations, because historical data was not available.		

Similar to previous studies (Dwivedi et al. 2014), coding of the main variables relied on information reported by the authors. This may be susceptible to the rhetoric employed in describing aspects related to novelty and theorization. However, an independent assessment of those knowledge claims may introduce even more subjectivity and bias. Mitigating concerns related to self-reported knowledge claims, it can be expected that reviewers and editors would require authors to correct exaggerated claims of novelty and theorization before publication. For novelty, the coding examples provided by Gregor and Hevner (2013, p. 348) served as a basis. For example, we coded (1) routine design when a “well-known solution is applied to a well-known problem”, (2) improvement when a “more fine-grained model or method” is proposed, (3) exaptation when systems development principles are “extended to a new class of information systems”, and (4) invention when “a new problem is conceptualized and addressed based on a novel solution”. For theorization, the coding was based on the components of design theories proposed by Walls et al. (1992). We coded (1) complete design theory when all components were addressed (not necessarily using the exact terminology of Walls et al. (1992)), (2) partial design theory when some components were described, or (3) nascent design theory when constructs, methods, models, design principles, or technological rules are presented that are more abstract than (4) instantiations, which are specific, and situated contributions at a low level of abstraction or theorization. The coding of theorization adapts the DSR contribution types presented by Gregor and Hevner (2013, p. 342).

Following established methodologies of qualitative content analysis (Neuendorf 2002), two of the authors coded novelty and theorization. During an initial training phase, the authors refined the coding scheme using the original classification results presented by Gregor and Hevner (2013) where applicable and subsequently coded the DSR papers. Both coding sets included an overlapping set of 30 DSR papers used to measure inter-rater agreement. Cohen's Kappa confirmed reliable inter-rater agreement with all coefficients exceeding the threshold of 0.6. Disagreements in the shared set of papers were discussed between the coders and reconciled by a third coder.

In line with other scientometric studies (Bornmann and Daniel 2008; Grover et al. 2013; Judge et al. 2007; Tams and Grover 2010), we control for journal-related effects using the 5-year journal impact factor provided by Thomson Reuters. Regarding author related effects, we use the h-index as a measure for author reputation (Hirsch 2005; Truex et al. 2009). Specifically, we control for the h-index of the first author of the DSR paper, since this is the most visible author of the paper and often receives the most credit (Peffers and Hui 2003). As the age of a publication plays an important role in accumulating citations over time (e.g., Mingers 2008), we also control for the number of years since publication of the DSR paper.

Results

Descriptive Statistics

The distribution of DSR papers over journals shows that five journals have published more than 90% of the DSR papers (Figure 3). Major topical clusters include business process management (8 papers), classification (7 papers), databases (7 papers), and software development (6 papers). Publishing DSR papers in top-tier information systems journals is a collaborative effort: While papers were published by 3.1 authors on average, our dataset contains only two papers that were published by a single author. Similar to the regional distribution of authors for other top tier journal papers, we observe a high proportion of authors from AIS region 1 (Americas: 60%), and lower proportions of authors from region 2 (Europe, Africa and Middle East: 24 %), and region 3 (Asia and Pacific: 16%). There are few authors from the German *Wirtschaftsinformatik* community who have published DSR papers in journals of the AIS Senior Scholars' Basket of Journals. Proportions of European and German authors are considerably lower compared to the DESRIST and BISE conferences (Fischer 2011; Leukel et al. 2014).

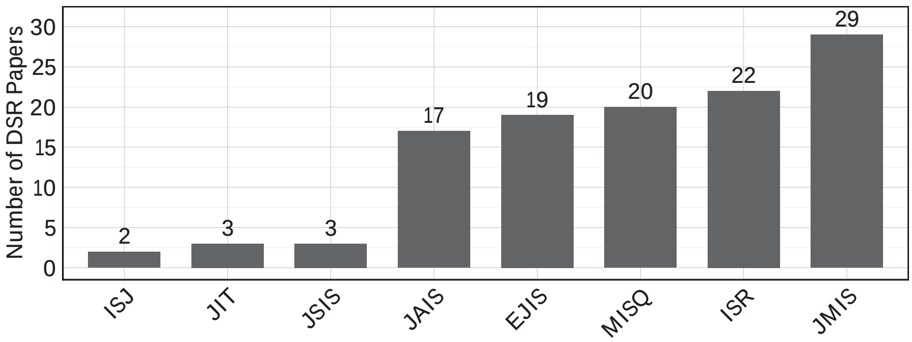


Figure 3. Distribution of DSR Papers (n=115)

Table 2 provides an overview of the top20 DSR papers with the highest scientific impact. It shows the coding for the two main factors of our model as well as the domain addressed by the papers. The domain labels were derived from the title, abstract, and keywords of the paper. The diversity of the papers is mainly accounted for by effects related to journal impact, author visibility, and age of publication, which are included as control variables in our model. Consistent with previous scientometric research in information systems (Hassan and Loebbecke 2010; Loebbecke et al. 2007), it is a relatively small number of DSR papers that achieve a substantial impact. Several DSR papers have only received single-digit citations.

Table 2. Top20 DSR Papers According to Scientific Impact				
Design Science Paper	**Domain**	**Novelty**	**Theorization**	**Citations**
Hanseth and Lyytinen (2010)	Dynamic complexity in information infrastructures	Improvement	Partial	339
Krogstie et al. (2006)	Quality of process models	Improvement	Nascent	290
Leimeister et al. (2005)	Trust in virtual health-care	Exaptation	Partial	231
Hickey and Davis (2004)	Requirements elicitation	Improvement	Nascent	213
Kohler et al. (2011)	Co-creation of user experience in virtual worlds	Exaptation	Partial	197
Sun et al. (2006)	Data-flows in business process management	Invention	Nascent	176
Arnott (2006)	Cognitive biases in decision support systems development	Exaptation	Partial	170
Pries-Heje and Baskerville (2008)	Multiple criteria decision making for wicked problems	Improvement	Partial	164
Sun et al. (2006)	Information systems security risk assessment	Improvement	Partial	162
Chau and Xu (2012)	Business intelligence in blogs	Improvement	Partial	161
Albert et al. (2004)	Managing content and interactivity of customer-centric websites	Improvement	Nascent	159
Lin et al. (2007)	Detecting mappings and differences between domain-specific models	Invention	Nascent	130
Abbasi and Chen (2008)	Text analysis of computer-mediated communication	Improvement	Complete	126
Adomavicius et al. (2008)	Analyzing trends in the IT landscape	Improvement	Partial	118
Kolfschoten and de Vreede (2009)	Facilitating collaboration in group support systems	Routine Design	Nascent	116
Rossi et al. (2004)	Managing evolutionary method engineering by method rationale	Improvement	Nascent	115
Germonprez et al. (2007)	Tailorable technology design	Invention	Partial	113
Adipat et al. (2011)	Presentation in mobile web browsing	Improvement	Partial	90
Parsons and Wand (2008)	Classification in conceptual modeling	Improvement	Nascent	83
Fan et al. (2005)	Web-based information retrieval	Improvement	Nascent	81

Regression Results

In contrast to several scientometric studies in information systems and other fields (Loebbecke et al. 2007), we find citation counts of DSR papers to be only slightly skewed (skewness: 0.68). We choose a negative binomial generalized linear model, which is appropriate for skewed distributions of count data. Applying a canonical logit link function allows us to account for the fact that our dependent variable deviates from the normal distribution in a similar way as (log)-linear models applied in other scientometric studies (Bertsimas et al. 2013; Grover et al. 2013; Mingers and Xu 2010; Tams and Grover 2010). As Table 2 indicates, the influence of outliers on citation counts needs to be analyzed. Although we originally did not exclude them from the analysis, to identify reasons for their high scientific impact, we checked the robustness of our model with respect to the exclusion of these outliers. Checks for correlations and multicollinearity of all variables were conducted examining correlation coefficients and generalized variance inflation factors (GVIF), which found that there are no problems with multicollinearity. All GVIFs are well below the threshold of 2, indicating that the factors are sufficiently unrelated and that collinearity does not influence the results. The following generalized linear regression model was specified:

$$log(citations) = \beta_0 + \beta_1 Journal\ impact\ factor + \beta_2 h\text{-}index + \beta_3 Age\ of\ publication + \beta_4 Novelty + \beta_5 Theorization + \epsilon$$

We present our results including coefficients and standard deviations in Table 3.

Table 3. Model Results (n=115)

	Estimate	z-Value
Journal impact factor (control variable)	0.31 (0.05)	6.03 ***
h-index (control variable)	0.03 (0.01)	2.77 **
Age of publication (control variable)	0.19 (0.03)	6.90 ***
Novelty [a]: routine design	0.22 (0.33)	0.66
Novelty [a]: exaptation	0.55 (0.19)	2.92 **
Novelty [a]: invention	0.47 (0.22)	2.12 *
Theorization [b]	0.38 (0.11)	3.39 ***
Nagelkerke R^2	0.47	

Notes. The model includes an intercept. Standard errors are in brackets.
Significance levels: *** indicates p<0.001, ** indicates p<0.01, * indicates p<0.05 (two-sided tests).
[a] Improvement was used as the reference group.
[b] The levels comprise nascent, partial, and complete theorization.

The resulting model explains 47% of the variance in citation counts (Nagelkerke R^2). In line with previous scientometric studies, our control variables are all significant predictors for the scientific impact. Even in the relatively homogenous set of journals we analyzed, DSR papers published in journals with a higher journal impact factor receive significantly more citations. Effects of author reputation and publication age positively influence citations on a significant level. Table 3 also presents results for the main variables.

The support provided for our hypotheses is summarized in Table 4. The results are based on the findings for the individual effects in Table 3. Overall, we find partial support for the effect of novelty on scientific impact, as postulated in Hypothesis 1. We do not find any confirmation for Hypothesis 1a, i.e., there is no evidence for routine designs receiving fewer citations than DSR papers categorized as improvement. Papers which apply a known solution to a new problem (exaptation), however, tend to receive significantly more citations (H 1b). Although at a lower level of significance, DSR papers which invent new solutions to a new problem also receive more citations than the reference group (improvement), providing evidence for Hypothesis 1c. In confirmation of H 2, we find that the level of theorization has a highly significant, positive effect on scientific impact.

Table 4. Overview of Support Provided for the Hypotheses		
Hypothesis 1a (-)	Scientific impact is lower for DSR papers focusing on routine design (applying known solutions to known problems).	Not supported
Hypothesis 1b (+)	Scientific impact is higher for DSR papers focusing on exaptation (applying known solutions to new problems).	Supported**
Hypothesis 1c (+)	Scientific impact is higher for DSR papers focusing on invention (developing new solutions for new problems).	Supported*
Hypothesis 2 (+)	Scientific impact is higher if DSR contributions are theoretical.	Supported***
Significance levels: *** indicates p<0.001, ** indicates p<0.01, * indicates p<0.05 (one-sided tests).		

Discussion

Based on our coding of the theoretical knowledge contributions and a subsequent citation analysis, this study uncovers the landscape of DSR papers and advances our understanding of what positions this type of paper for maximum scientific impact. Alleviating common critique of lacking insights in scientometric studies (Goes 2015; Straub 2006), we deliberately discuss how the implications of our work can be projected on an overarching context by outlining explicitly how our insights relate to the ongoing discourse on DSR. Finally, we make limitations of our work transparent and discuss to what extent they could be addressed in future research.

The Most Influential DSR Papers and Theories

One contribution of this paper is taking stock of the most influential DSR papers and theories published in pertinent information systems journals (cf. Table 2). In particular, we make the level of theorization associated with the plethora of DSR contributions transparent. All DSR papers provide nascent theoretical contributions by developing constructs, models, or methods (Gregor and Hevner 2013). 18 papers develop theoretical contributions that partly meet the criteria advanced by Walls et al. (1992), and six papers present design theories that include all components described by Walls et al. (1992). These include design theories for computer-mediated communication text analysis systems (Abbasi and Chen 2008), social recommender systems (Arazy et al. 2010), secure information systems design methods (Heikka et al. 2006), systems supporting convergent and divergent thinking (Müller-Wienbergen et al. 2011), modeling and estimating service response time in enterprise architectures (Närman et al. 2013), and win-win negotiation agents (Yang et al. 2012). These theoretical contributions may instill confidence that theorizing is gaining traction in DSR – even more so, if we consider Dwivedi et al.'s (2014) contention that generating strong theory cannot be expected from all DSR papers. Similarly, the degree to which the identified DSR papers interact with existing bodies of descriptive knowledge – as one aspect of theorization, or information systems design theory – indicates a healthy grounding in extant research. This observation differs from previous surveys of DS conferences (e.g., Leukel et al. 2014). With our analysis of influential DSR papers, we contribute to addressing the lack of a systematic overviews of DSR (Fischer 2011). By identifying those DSR papers that formally include the components of an information systems design theory (Walls et al. 1992), our study can also be seen as an extension of Walls et al. (2004), who reviewed the DSR literature published between 1992 and 2004 and found four papers that present a design theory. Compared to existing surveys that have criticized the lack of theorizing in DSR (Arnott and Pervan 2012; Dwivedi et al. 2014; Gaß et al. 2012), our insights into DSR published in top journals may indicate a beginning shift toward stronger theorization.

In reflecting on this contribution of our study, we believe that it is useful to conceive the intellectual foundation of DS as comprising two (intertwined) parts: (1) Methodological, meta-level, theoretical, philosophical and epistemological papers, and (2) research papers that directly contribute to the production of DSR domain knowledge[5]. While existing co-citation analyses (Fischer 2011; Piirainen et al.

[5] These papers are sometimes referred to as DSR application papers (Fischer 2011).

2010) have proven to be appropriate to identify the first part of the intellectual foundation, our methodology is appropriate to identify influential design-oriented research papers. In a nutshell, we identify DSR papers that actually do DSR and not those papers describing how DSR should be done. Our study can be seen as a first step towards appreciating seminal theoretical DSR contributions and to dissociate them from less theoretical, more context-specific, or idiographic (Baskerville et al. 2015) papers. In the words of Lakatos (1976), our insights could be interpreted as useful in distinguishing the *hard core* of design theories from design research that constitutes a *protective belt* of auxiliary, observational or idiographic (Baskerville et al. 2015) nature. Further, and consistent with Weber (1987), an underlying notion of our study is that scientific impact is indicative of the overall progress in a research field that has established a cumulative tradition. Based on this notion, we expect an integrated view of both dimensions of the intellectual foundations to enable us to answer questions pertaining to the identity of DS as part of the information systems community (Agarwal and Lucas 2005; Benbasat and Zmud 2003; DeSanctis 2003; Galliers 2003; Klein 2003; Robey 2003; Weber 2003). Understanding the underlying philosophical and methodological works as well as being able to point to influential theoretical papers is valuable for substantiating claims regarding the impact and legitimacy of design science in information systems.

An Explanation of Scientific Impact and Its Implications

Building on the inventory of influential DSR papers, the second contribution of this paper is to provide insights into the factors that explain scientific impact. Specifically, our model shows that after controlling for journal, author, and time-related effects, the level of theorization and the type of novelty considerably affect the scientific impact of DSR papers. Support for Hypothesis 2 indicates that every level of theorization beyond the common contributions of constructs, models, and methods (nascent theorization) is associated with a significantly higher number of citations. Although developing complete design theories that include all four components described by Walls et al. (1992) might be considered too challenging for some DSR papers, our results indicate that even proposing partial design theories makes a difference. This could be accomplished by substantially and explicitly drawing on kernel theories from existing descriptive bodies of knowledge (Gregor and Hevner 2013; Walls et al. 1992) or by deriving formal hypotheses that are useful for evaluating whether the design contribution achieves its goals (Walls et al. 1992). Regarding the types of novelty, DSR papers classified as exaptation or invention attract significantly more citations (Hypotheses 1 b, c), suggesting that researchers generally value these types of novelty. Concerning routine design, which is sometimes considered as no major knowledge contribution (Gregor and Hevner 2013), we did not find evidence for a lower scientific impact (Hypothesis 1 a was not supported). This is consistent with the idea that DSR papers of low novelty might also have their merits – a stance supported by the fact that these papers have survived the peer review process at some of the most prestigious information systems journals. From the perspective of practitioners, a certain focus on known, existing problems and established solutions might be valuable to ensure that research outputs are more readily applicable in a certain context and provide more immediate utility. Conversely, although the scientific domain evidently values exaptation and invention, we expect the maturing process of novel design artifacts and subsequent trajectories into practice to be less immediate.

A related aspect which merits further discussion in light of our findings is the evaluation of DSR papers vis a vis papers of other genres, which has implications for debates on the relative standing of the DSR community in the information systems discipline. Recurring themes in these debates include the following: design impact is not rewarded sufficiently (Gill and Hevner 2013), evaluation standards do not adequately reflect the "perceived centrality of design for the discipline" (Gleasure et al. 2012, p. 2), and top tier information systems journals should apply different criteria for DSR papers (Österle et al. 2011). These calls for a stronger acknowledgement of DSR at least partly reflect that DSR paper differ in their ability to generate scientific impact, potentially skewing hiring funding and promotion decisions (Niederman et al. 2015). While one approach would be to develop complementary measures for impact on practice (e.g., Gill and Hevner 2013), our paper acknowledges the central importance of scientific impact in academic evaluation processes. Putting aside limitations which are inherent in every measure of scientific impact, an advantage of this approach is that it is more appealing to researchers and academic evaluation committees (Gill and Hevner 2013). In this regard, we provide evidence that enables funding bodies and hiring committees to better gauge and appreciate the (relative) impact of DSR. Put differently, it makes the standards transparent against which DSR should be evaluated. Specifically, conceptual or methodological papers – such as the paper of Hevner et al. (2004), which has been cited more than 300 times after 2 years – have a much broader applicability and do not provide an appropriate standard for comparing and evaluating DSR papers.

Although our study focuses on citations as a specific type of impact, we consider it to have broader implications. Critically, we expect high direct impact of design science to be indicative of increased diffusion of the original DSR contributions through subsequent research projects (Swanson 2014). This suggests that efforts to gauge different types of direct or immediate impacts should critically reflect on the limitations introduced by excluding indirect influences that materialize through other papers. In particular, this might underestimate the importance of theoretical DSR papers that are too theory-centric or abstract to have an immediate impact on practice but provide a foundation for multiple subsequent projects that provide high practical utility. For instance, we would be surprised to find the paper on relational database theory (Codd 1970) sitting on the desk of an industry database maintainer. Instead, it would be more likely to find a MySQL manual that draws on papers on query languages, which in turn are influenced by relational database theory. Similarly, the impact of DSR papers can take the educational route and diffuse into teaching practices, which is exemplified by the fact that Codd's work is pervasive in today's database curricula. These examples illustrate that assessing the extent and causality of impact is an open challenge (Niederman et al. 2015). Therefore, understanding what it means to conduct high impact design science research in information systems requires us to go beyond measures of immediate impact that are objective and easily to defend (Niederman et al. 2015) and consider multiple facets and paths of impact – a goal unlikely to be accomplished by a single study.

Further Research

As we consider the impact of DSR papers to be worthy of further investigation, we briefly discuss the limitations of our work and discuss whether they provide promising paths for further research. Our results are not representative for DSR research output in general, as our analysis is limited to a 10-year output of the AIS Senior Scholars' Basket of Journals. It does not cover conference proceedings, other journals, or a broader scope of time. Including conference proceedings would raise the challenge of controlling for publication outlet related effects, i.e., there are no impact factors for conferences. Another issue pertains to differences in types of papers that might arise from page limitations or differing publication standards (Leukel et al. 2014). These differences require careful assessment of heteroscedasticity to ensure that pooling papers from different publication outlets is warranted. We expect this to be more problematic for conference proceedings than for other high quality design research journals, which provides an opportunity to extend the scope of the dataset. Regarding the time scope, we must allow for a reasonable time until the impact becomes evident. We plan to extend the time scope to papers published before 2004.

The correlational nature of our analyses limits the degree to which inference of causality is warranted. This limitation is inherent to almost all analyses of scientific impact, since "impact causality [of research] is difficult to establish and to evidence" (Niederman et al. 2015, p. 131). Similar to Mingers and Xu (2010), we have to acknowledge that scientific impact arises from probabilistic processes and complex interactions, which do not lend themselves to experimental designs.

Beyond novelty and theorization, additional aspects might be suspected to affect scientific impact of DSR papers. In particular, the importance of evaluation activities has been emphasized prominently (Hevner et al. 2004; March and Smith 1995). Based on the comprehensive taxonomy provided by Prat et al. (2015), extended analyses indicate that our set of DSR papers employs a whole arsenal of different evaluation approaches. Similar to DSR papers which have not been cited often, influential ones cover the range of quantitative and qualitative evaluation methods, including informed arguments (Hanseth and Lyytinen 2010) and illustrative scenarios (S. X. Sun et al. 2006). Some even defer evaluation to further research (Müller-Wienbergen et al. 2011). Put differently, we did not find a sufficiently general category of evaluation that allowed us to draw conclusions whose generalizability can confidently be claimed to reach beyond our specific set of DSR papers.

Complementary studies might explore different units of analysis and dependent variables. While we focus on single DSR papers as the unit of analysis, one opportunity for future research would be to consider broader DSR projects. Which characteristics distinguish projects that produce a higher (cumulative) impact through DSR papers? Databases of funding bodies, such as the National Science Foundation[6], provide valuable starting points for corresponding studies. Finally, while we have focused on scientific impact as one particular type of impact, other types of impact (cf., e.g., Niederman et al. 2015; Swanson 2014), most notably impact on practice (cf., e.g., Gill and Hevner 2013), merit further research. In particular, there is a need for better understanding how DSR papers impact different stakeholders, such as information systems practitioners, managers, or policy makers. Although measuring the impact on practice is an open challenge, assessment techniques would be invaluable for DS researchers (Niederman et al. 2015). One starting point could be to code the perceived relevance or "likely extent of use", as suggested by Arnott and Pervan (2012, p. 932). A more nuanced understanding of different types of impact deems valuable to inform publication practices of DSR papers. Further research questions could be: Are there trade-offs authors should be aware of? Do different components of this paper type have "conflicting implications for impact?" (Tams and Grover 2010, p. 168).

Conclusion

Our study offers two unique contributions that are valuable for the DSR community and its pursuit of developing an impact on society. First, based on the dataset of Prat et al. (2015), we have coded DSR papers published in top-tier information systems journals between 2004 and 2014. This effort provides in-depth insights into the overall landscape of DSR papers, and the emerging body of DSR knowledge that comprises nuanced research outputs of varying types of novelty and levels of theorization, such as instantiations and formal DSR theories. Most notably, contributions to DSR theory are not evident in extant surveys of DSR. Second, we developed a model that draws on the two complementary theories of citing behavior to analyze factors that explain the scientific impact of DSR papers. Our results suggest that DSR papers achieve a higher impact when they (1) address novel problems based on existing or new solutions (exaptation and invention), and (2) make theoretical knowledge contributions.

We hope that our distinct insights and contributions are useful for various stakeholders of DSR. For doctoral students and those who are relatively unfamiliar with DSR, we provide a systematic overview of influential research contributions. Primary insights for prospective authors of DSR are provided by our analysis of factors that position DSR papers for maximum scientific impact. Furthermore, prospective authors could benefit from our work when they search for exemplary DSR papers to understand established DSR research designs, polish their manuscripts, and target them towards appropriate journals. Finally, we provide a unique resource for the information systems community and its funding bodies to appreciate the range of DSR papers and their differences in scientific impact.

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[6] http://www.research.gov provides a list of DSR projects if filtered for program type "Science of Design".

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