Instruments of Inquiry: *Understanding the Nature and Role of Tools in Design*

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Designers employ a range of tools in most design projects, yet there are few frameworks for understanding how and why they work. On the basis of a well-established school of thought, pragmatism, this paper contributes with a coherent conceptualisation of tools in design, which I label *instruments of inquiry*. This perspective underscores the crucial role that instruments play in design, and the ways in which they support design creativity and exploration. In particular, it highlights that instruments not only augment designers' capabilities for carrying out intended actions, they also guide their perception and understanding of design problems and solutions. I present and discuss a framework consisting of five qualities of *instruments of inquiry*, which make them valuable in designerly inquiry: *perception, conception, externalisation, knowing-through-action*, and *mediation*.

Keywords – Design Theory, Analytical Frameworks, Creativity, Design Tools, Pragmatism, Designerly Inquiry.

Relevance to Design Practice – Provides a coherent conceptual framework for understanding the nature and roles of the tools that designers employ in practice. This can help designers develop their competence, e.g., by rethinking how they can use tools to get a better understanding of a design challenge or support the generation of novel solutions.

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Introduction

The use of tools pervades most forms of interaction design practice. Not only do designers employ them to create future products and services, they also draw upon them to understand the design situation and the problem at hand, and to explore and experiment with potential solutions. Scholars have examined many particular roles that tools can play in the design process, e.g., the use of sketching tools to conceive and give form to future products (Buxton, 2007), the use of visualisation tools to explore data sets (Shneiderman, 2001), the potential of mock-ups to offer hands-on experiences of future products (Ehn & Kyng, 1991), and the role of prototypes to act as filters and manifestations of potential design solutions (Lim, Stolterman, & Tenenberg, 2008). This notwithstanding, there are few examples of overarching theories of the nature of tools in the design process, despite a recognised need to further develop the understanding of the specific characteristics and qualities of design (e.g., Kimbell, 2011; Rogers, 2004; Stolterman, 2008).

The aim of this article is to add to our understanding of the role and nature of tools in design. We will do so by examining tools in design through a particular analytical lens, namely pragmatist philosophy. The motivation for choosing pragmatism to scrutinise tools in design is that this perspective has recently been revitalised in design studies, and, as examined in a recent article here in the *International Journal of Design*: "there is a large degree of convergence between the pragmatist perspective and design thinking" (Dalsgaard, 2014, p. 143). However, an interesting façt of pragmatism that has not yet been examined in the context of design is that it offers rich understandings of the role of technology in creative and exploratory activities to the extent that it can be considered a *philosophy of technology* (Hickman, 2001). A pragmatist examination of tools in design thus has the benefit of building upon an already recognised theoretical approach in design and expanding it to encompass the role and nature of tools, a phenomenon that is crucial, yet theoretically underdeveloped, in design research. I will build on two central concepts in pragmatism, namely *inquiry* and *instruments*, and examine the potentials of articulating tools in design as *instruments of inquiry,* which not only augment designers' ability to carry out certain actions, but also augment their cognitive abilities to see and understand certain design opportunities, conceive of and evaluate possible solutions, and bring potential futures into form so they can be examined and communicated.

The main contribution of the paper is the development of a conceptual framework for *instruments of inquiry*, and an explication of five qualities of instruments of inquiry: *perception, conception, externalisation, knowing-through-action,* and *mediation*. At its core, this is a theoretical contribution to the understanding and articulation of design. However, it can also have implications in design practice, e.g., by helping designers understand how and why certain tools work in certain situations,

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or helping them select or modify tools to fit the specific design challenges at hand. The five qualities of instruments of inquiry can each yield insights into specific aspects of design tools that are pertinent in a given design situation; however, the main benefit in sum is that they form a coherent framework, which can offer a more nuanced understanding of how and why certain tools do or do not work in certain situations. On a more concrete level, this can help designers develop competence in using these instruments, e.g., by looking at how they specific ways of employing an instrument can help get a better understanding of a design challenge, support the generation of novel solutions, or help communicate with other stakeholders in a design process. As the examples at the end of the article will demonstrate, the pragmatist perspective underscores that an important part of design competence is knowing how to modify existing instruments to fit specific design challenges, or even to develop new instruments if the situation calls for it.

The structure of the article is as follows: Firstly, I offer a brief overview of related work on design tools and outline the basic tenets of pragmatism. I then focus on the pragmatist understanding of *inquiry* and *instruments* in order to develop and discuss the concepts of *designerly inquiry* and *instruments of inquiry*. On this basis, I explicate and discuss five qualities of *instruments of inquiry*: *perception, conception, externalisation, knowing-through-action*, and *mediation*. Finally, I discuss how an understanding and mastery of instruments is a crucial aspect design competence, how design situations often require the development of novel instruments, and the implications of adopting different perspectives on tools in design.

Related Work: *Tools in Design*

The functions of the tools in design practice have been examined in quite an extensive body of work. It is beyond the scope of this paper to offer more than a brief overview of this work, hence I will highlight contributions that represent the breadth of it.

Buxton (2007) has examined the use of sketching tools and their importance, proposing that sketching is a quintessential design activity, from the very beginning of a project as the first ideas emerge and throughout the design process as a means of refining and developing the concept. In early phases of design projects, sources of inspiration are often also introduced in a tangible format, as is the case with many card-based design techniques (Wölfel & Merritt, 2013). As design concepts take shape, mock-ups (Ehn & Kyng, 1991) can offer hands-on experiences and insights about potential future products. Even more widespread is the use of prototypes, ranging from low-fidelity paper prototypes to highly functional, near-product iterations, which can, among other things, act as manifestations of design concepts and filter salient aspects for designers to examine (Lim et al., 2008). A range of tools for coordinating and managing collaborative design complement these tools, and are examined at length in Computer-Supported Cooperative Work (CSCW) literature (Bannon, 1993).

In addition to these studies of specific forms or functions of design tools, there is a smaller body of literature that seeks overarching understandings of their role and nature. Bertelsen (2000) builds upon Activity Theory to develop an epistemology of design artefacts, underlining the roles they play in supporting construction, cooperation, and conception. Klemmer, Hartmann, and Takayama (2006) draw upon a multitude of theories, including embodied cognition (Pecher & Zwaan, 2005), to discuss the power of artefacts to support learning, concept development, coordination, and performance. In a similar vein, Djajadiningrat, Wensveen, Frens, and Overbeeke (2004) argue for an increased acknowledgement of the embodied aspects of interaction design and the role of physical design artefacts, inspired by Gibson's theory of ecological perception (Gibson, 1986). Dix and Gongora (2011), building in part also upon ecological perception and embodied cognition, offer a more encompassing understanding of externalisation in design, ranging from art and architecture to industrial design and programming.

While all of the above contributions have to some extent informed this paper, the work presented here falls in the latter category of theoretical conceptualisations of design tools. This paper complements the existing body of research through the concept of *instruments of inquiry*, which focuses on the roles that design tools play in *designerly inquiry* through helping designers see, understand, explore, and experiment. This paper examines the intertwined and co-evolving relation between the design process and the tools employed in it, and adds to the development of pragmatism as a framework for understanding design processes.

A Pragmatist Perspective on Designerly Inquiry and Instruments

Pragmatism denotes a school of thought that originated in the United States around the beginning of the 20th century. Several scholars, including Charles Sanders Peirce (1839-1914), William James (1842-1910), John Dewey (1859-1952), and George Herbert Mead (1863-1931), are attributed with founding pragmatism. In this paper, I focus on the Deweyan strand of pragmatism, since several of his key concepts, including inquiry and technology, are particularly apt for understanding creative design and the role of tools in it. Some Deweyan concepts may already be familiar to design researchers and practitioners, since his works have influenced design scholars, including Schön (1983). Recent years have seen a renewed interest in revitalising and recontextualising pragmatism in interaction design research, and this paper can be seen as a continuation of this work.

Pragmatism considers a strong division between theory and practice untenable, and posits that the two are intertwined: theories and conceptualisations are formed as a means for comprehending

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and acting in the world, often in an attempt to alter or modify the current conditions, and their value is determined by how they help us cope in practice. At the same time, the world around us evolves, in part because we try to shape and change it according to theories and conceptualisations; in the words of Shalin (1986, p. 10), it is "brimming with indeterminacy, pregnant with possibilities, waiting to be completed and operationalized." It is an essential part of human behaviour to seek to understand the evolving world, to form ideas and hypotheses about how to act in it and to shape it, to experiment with these ideas in practice, and to actively engage with in order to change it. In Deweyan terminology, this is a process of *inquiry.* While Dewey did not specifically address design as a field, the emphasis of situatedness, emergence, transformation, and inquiry in his works have inspired a number of more recent contributions, since they echo concerns in interaction design and creativity. For example, I have argued that Deweyan pragmatism offers "well developed and coherent articulations of concerns that are central to design thinking" (Dalsgaard, 2014, p. 143). In a similar vein, Hartmann et al. (2014) draw upon pragmatism in the exploration and development of digital simulation tools, as does Steen (2013) in the study of co-design of multimedia tools and communication. These contributions are very recent and of clear relevance to the design community, but there are several other works that bring together pragmatism and design, including Buchanan (1992), Dalsgaard (2008, 2009), Hansen and Dalsgaard (2012), McCarthy and Wright (2007), and Petersen, Iversen, Krogh, and Ludvigsen (2004).

The following discussion focuses on two concepts of Deweyan pragmatism central to this paper; *inquiry* and *technology*[1]. I will use this pair of concepts as the basis for the conceptualisation of *designerly inquiry* and *instruments of inquiry*. The latter constitutes the main contribution of the paper, and I will draw out five qualities of *instruments of inquiry—perception, conception, externalisation, knowing-through-action,* and *mediation*—which can scaffold design analysis, inform designers' choice of tools, and potentially lead to new tools for design. The objective is not to reject nor replace existing understandings of tools in design, but to develop and enrich the discourse by examining how the pre-existing and well-developed conceptual framework offered by pragmatism can add to the understanding of instruments in design. In addition to the epistemic contribution of better understanding tools in design, a framework like this offers three benefits: Firstly, it can provide a foundation for structured critical *analysis of existing tools employed in design*. Secondly, it can yield a better basis for *selecting and employing tools in a given design practice*. Thirdly, it can offer a starting point for *planning and developing new tools that better support design,* or potentially *enable novel forms of design*.

Designerly Inquiry

Inquiry is described by Dewey (1938) as:

> ... the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituents distinctions and relations as to convert the elements of the original situation into a unified whole... The resolution of a problematic situation may involve transforming the inquirer, the environment, and often both. The emphasis is on transformation. (p. 108)

Inquiry commences when individuals are confronted with a situation that is somehow unsatisfactory or uncertain and decide that they want to change it. While Dewey describes inquiry as a general mode of human activity, this echoes the initial process of many creative design projects, in which designers encounter a problem. This instills the motivation for transforming the situation. It is followed by a process of framing and examining the characteristics of the problem and understanding the space of opportunities and constraints that it entails. This leads to hypotheses about how the situation might be transformed. These hypotheses are then explored, both through reflection and action, in order to determine how to carry through the required changes in order to bring the situation towards a more desirable state. When these changes are implemented, the problematic situation may be resolved, or it will be clear that there is still work to be done, in which case the process of inquiry can continue. Due to the complex nature of most creative design projects, it is rare that they are resolved in a straightforward manner. Often, the resolution of a problematic situation is an ongoing, iterative process that cycles between problem framing and articulation, hypothesis generation and practical evaluation. Addressing one component of the situation may cause other components to change in unforeseen ways, necessitating a reformulation and reframing of the problem, which in turn leads designers to conceive of new solutions. The iterative process of designerly inquiry can be illustrated as in Figure 1:

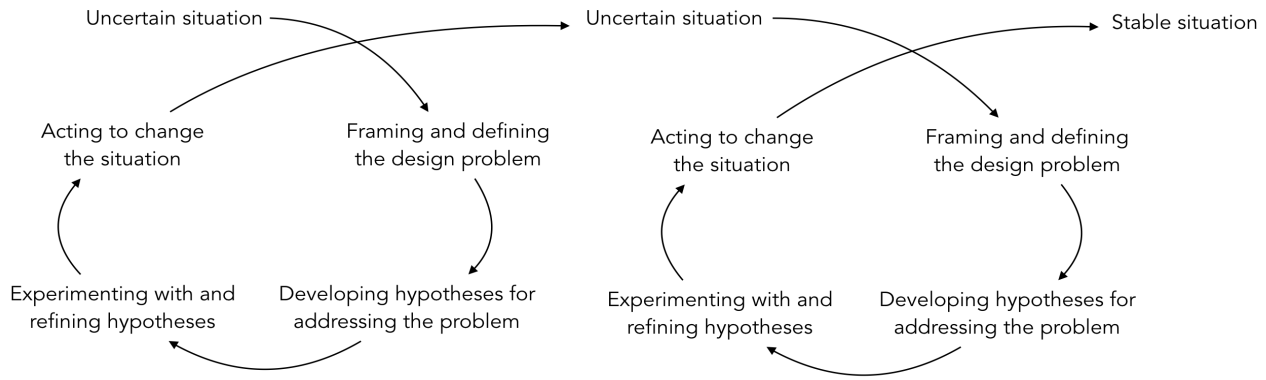

Figure 1. A model of iterative designerly inquiry.

Following this, a creative design process can be considered an archetypical example of inquiry. I define *designerly inquiry* as *an explorative and transformative process through which designers draw upon their repertoire of knowledge and competences as well as resources in the situation, including instruments, in order to create something novel and appropriate that changes an incoherent or undesirable situation for the better*. Here, I draw upon the widely accepted characterisation of creativity as the act of bringing forth something that is both novel and appropriate (Sternberg & Lubart, 1999), as well as the notion of design as the process of addressing wicked problems (Buchanan, 1992). In this understanding, design can be seen as a field concerned with finding novel and useful ways of approaching and transforming uncertain situations in which there are no straightforward answers. I use the term *designerly* in the same manner as Cross (1982), i.e., to designate that which pertains to the particular field of design.

Designerly inquiry is a reciprocal process in the sense that the various components of the situation interact and affect one another. Schön and Bennett (1996) has examined this in detail through the metaphor of design as an ongoing dialogue with the situation, which 'talks back' to the designer. From this follows the understanding that creativity, in a pragmatist perspective, is not solely a cerebral activity. It is instigated by and–to varying degrees–directed toward environmental conditions, and it is embodied and externalised through the act of creating. Design creativity is thus an emergent and situated phenomenon that comprises both action and reflection, and which arises as an interplay between the designer and the design situation.

In Deweyan terms, a situation is the assemblage of subject and surroundings, including people, socio-cultural constructs, physico-spatial surroundings, and artefacts. When we transform the situation via inquiry, it can happen through shifts and changes within and across all of these components. In a design perspective, this means that the resolution of a design problem will often entail more than, for example, the introduction of a new technology; it also means that designers develop their understanding of the domain, that a proper fit is developed between the technology and context within which it is introduced, and that people in the domain acknowledge, adopt, and adapt to the system. In some instances, this process may even lead designers to realise that the reason they saw a problem in the first place was that they had too little insight into the domain, and as they learn more about it, they may see that it might not be beneficial to introduce new technologies. In the latter situation, the perceived problem is thus resolved, not through a transformation of the other constituents of the situation, but through a transformation of the designers as they expand their understanding of the situation.

Instruments of Inquiry

Technology plays a crucial role in inquiry, and Dewey himself employed the term *instrumentalism*, rather than pragmatism, as a label for his work, underscoring the importance of how thinking and doing is supported by instruments. In order to clear up terminological misunderstandings, it should be noted that Dewey broadly defines *technology* as the use of instruments to reach an intended outcome. The concept of *instrument*, in this perspective, is both *unifying*, in that it can denote a range of artefacts; and *relative*, in that it can be any artefact that is employed as a means to transform the situation. That is, an artefact becomes an *instrument of inquiry* when we use it as such, and the value of it lies in how well it supports the process of inquiry. In the remainder of this paper, I will use this definition of instrument. Hickman, who has examined the role of instruments in Deweyan inquiry at length, emphasises that they not only serve as tools to carry out specific actions, but that they also help us understand and examine the problem at hand:

> At the conscious level, inquiry takes its start in situations that are doubtful, from which it seeks to shape well defined problems. It then uses tools of all sorts, abstract as well as concrete, to form hypotheses which it tests in the very existential arena from which the motivating difficulty arose. (Hickman, 2007, p. 37)

Instruments of inquiry can consequently be defined as instruments that scaffold the process of inquiry. The development of such instruments is an integral part of human activity, and *the ongoing development of instruments of inquiry iteratively extend our capabilities to observe and comprehend*: "The important thing in the history of modern knowing is the reinforcement of these active doings by means of instruments ... devised for the purposes of disclosing relations not otherwise apparent" [Dewey 1925-1953 p. 70]. Although *instruments of inquiry* in some instances function as tools that help us reach a specific outcome, they are not limited to being a means to an end, something that we employ to facilitate our actions in the world once we have a pre-formulated plan for how to transform the situation. They also affect our perception and understanding of the world, and help us explore and make sense of it. Technology is always present, both in our repertoires and habits formed from past experience, and in numerous forms in our surroundings. The pervasive nature of technology means that it also frames, directs, and scaffolds our experience of the world: "... technological arts, in their sum total, do something more than provide a number of separate conveniences and facilities. They shape collective occupations and thus determine direction of interest and attention, and hence affect desire and purpose" (Dewey, 1934, p. 345). For example, the use of a computer can be seen as a functional means to an end: you use it to record words and sentences that you have formed in your head. This may hold true when you first use a computer; however, repeated use of a computer is likely to alter the way you think about and engage in the writing process through the changes it effects on seemingly functional levels. This has been explored by e.g., Johnson who writes of the experience from an author's perspective: "The computer had not only made it easier for me to write; it had also changed the very substance of what I was writing, and in that sense, I suspect, it had an enormous effect on my thinking as well" (Johnson, 1997, p. 145). I use this example of a computer to illustrate that even tools that are widely considered to be functional tools in fact frame and shape the inquiry in which they are employed; in this case the computer not only gives the writer

access to new functions; the availability of these new functions and the writers' eventual mastery of them also changes how the writer thinks about the process and product of writing.

To further develop and refine the *instruments of inquiry* framework, I will explicate five qualities of particular importance for design: *perception, conception, externalisation, knowing-through-action*, and *mediation*. These qualities have been developed and articulated over the course of a decade in an interplay between taking part in concrete interaction design projects and developing understandings of design through the lens of pragmatism. While Dewey developed pragmatism by applying it to a range of disciplines, including education, art, and logic, he never applied it to design. However, he strongly emphasised the need for pragmatism to continuously be applied to contemporary topics, both to constantly put it to the test and to further develop it. Our research lab's involvement in real-life design projects has made it clear that tools play a crucial role in design practice. The five qualities have thus emerged both through readings of pragmatism, observations of design practice, and iterative articulations in which several versions of the qualities and have been developed, and their explanatory power in concrete cases has been evaluated.

While the five qualities are often intertwined in practice, I find it productive to articulate them separately for analytical and explanatory purposes. Not all *instruments of inquiry* embody all five qualities. Some are developed or employed for a singular purpose, while others can serve a wider range. The five qualities probably resonate with design researchers and practitioners to some extent. They are not intended as a radical rethinking of design, but as a coherent framework that can complement existing insights, both from pragmatism and other theoretical perspectives. For this reason, I also draw in other sources for each quality to show connections to related work. Moreover, I will exemplify each quality with cases from our own work in the field of media architecture. Media architecture is an emergent discipline, in which the fields of interaction design and architecture merge in the development of architectural structures with integrated interactive elements (Dalsgaard & Halskov, 2010). Our research lab, CAVI (Halskov, 2011), has carried out a range of media architecture projects in recent years and systematically collected data on the design processes. Media architecture is a nascent field with few well-established methods and instruments; as a consequence, we have had to develop a series of new instruments to support designerly inquiry, in addition to using and/or modifying existing instruments. While this has presented a number of practical problems, in a research perspective it has the advantage of prompting us as to carefully consider the role, purpose, and nature of these instruments.

Perception

*Instruments of inquiry enable and support **perception**, revealing facets of a design situation that would otherwise be hidden, while obscuring other facets. By knowing what an instrument reveals and what it hides, a designer can use these constraints to establish a stronger focus on designated design problems*.

The initial phase of *designerly inquiry* is concerned with perceiving and understanding the design situation and formulating the design problem. In many cases, this is not a trivial matter. Many design situations are rich with wicked problems (Buchanan, 1992), and they can be framed in different ways. It is a well-established assumption that designers' perceptions and approaches to design problems is influenced by their pre-existing knowledge; however, they are also highly influenced by the *instruments of inquiry* that they rely upon. The most widely known example of this is notion of Maslow's hammer and its inherent criticism of naïve instrumentalism: "I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail" (Maslow, 1966, p. 15). In addition to framing how designers see a problem, instruments can also shape the ways in which they subsequently think about solving them, as demonstrated in the examples from the previous section of how different instruments for writing implicitly influence how we think about writing. This understanding of the dual side of *instruments of inquiry*—that they not only act as extensions of our capabilities but also frame and guide our perception and understanding—is analogous to the concept of *constraints* from recent contributions to creativity research. Constraints, which have typically been defined as limitations on action (Vandenbosch & Gallagher, 2004), are here reframed as integral to creative design, serving a dual role of both enabling and restraining what designers can do (Onarheim & Wiltshnig, 2010). This corresponds to how *instruments of inquiry* both enable and restrain our perception and understanding of a design problem and the potential solutions to it. Given the central role of *instruments of inquiry* in design, a key competence for designers is to master the tools of their trade. In continuation, a crucial part of learning to master an instrument is developing a familiarity with both the restraining and enabling aspects of it, and knowing when and how to use different instruments that can help to reframe the problem at hand.

As an example from our work on media architecture, our research lab, CAVI, collaborated with an architectural firm, Bjarke Ingels Group, and an advanced lighting manufacturer, Martin Professional, in a project spanning several years to design and build the Danish pavilion (see Figure 2) for the 2010 World Expo in Shanghai. The case is described in more depth in Dalsgaard, Halskov, and Wiethoff (2016), and Halskov and Ebsen (2013). The form of the pavilion, a very distinct shape akin to a Möbius strip, had already been decided by the architects, and our task was to develop a media façade that spanned the building's exterior. CAVI had mostly worked with rectangular media façades in the past, and the Pavilion's helical shape was so unorthodox that it was very hard for us to grasp how visual content would appear on the façade. *We needed an instrument to enable us to perceive and understand the design problem at hand*, so CAVI developed a 3D model of the Pavilion. The building was perforated by 3600 holes, and we proposed to embed circular LED lights into each hole, in effect creating a very elongated, low-resolution display. The 3D model had an exact configuration of the 3600 pixels from the architects' specifications (see Figure 7). To visualise how content on the façade would appear, we had to develop software that would enable us to change the colours of the individual pixels in real time and visualise the tubular shape of the pixels.

Figure 2. The Expo Pavilion media façade at night.

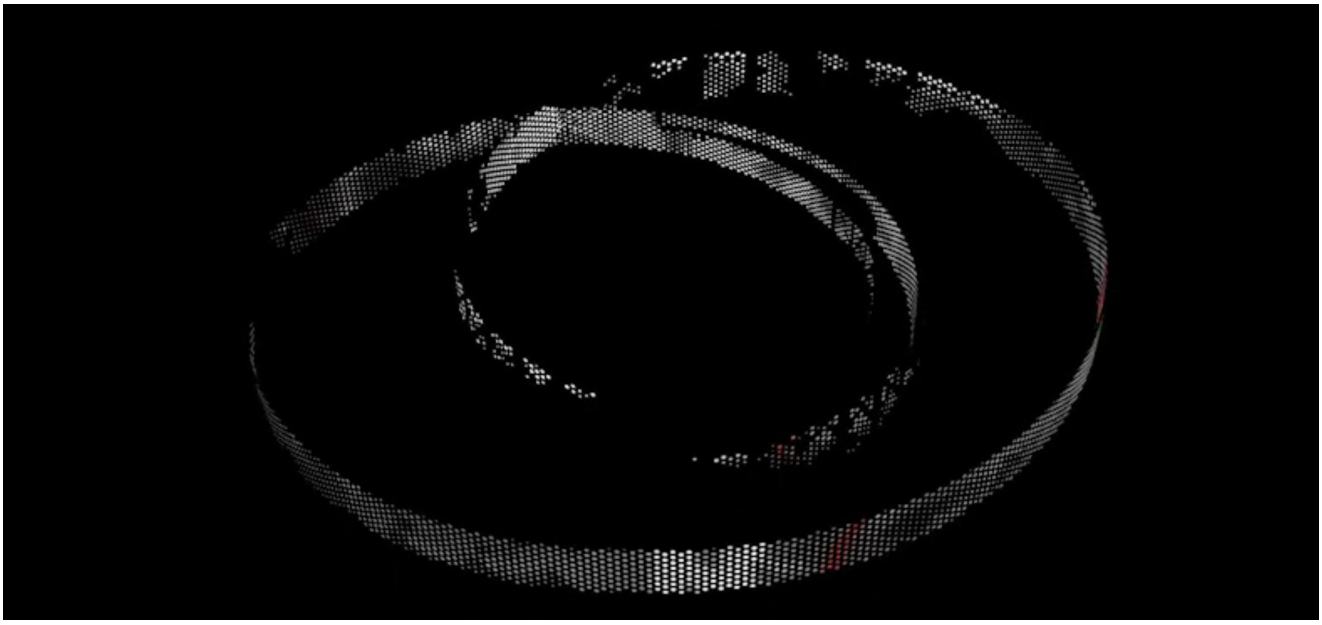

Figure 3. The 3D model visualises the pixel configuation of the expo pavilion façade.

Conception

Instruments of inquiry enable and support ***conception****, helping designers understand and articulate the problems they face, develop hypotheses about how they might address these problems, and examine and revise these hypotheses. Some instruments do this in abstract, semiotic forms, others in concrete and tangible ways.*

After the initial perception and framing of a design problem comes a phase of forming, exploring, and potentially revising hypotheses about how the situation may be resolved. Depending on the given situation, a hypothesis can range from over-arching notions of how to frame and approach a problem to specific concepts. As outlined above, many instruments often indicate specific ways of addressing design problems and as such guide the formation of hypotheses. Some instruments, however, are specifically suited, and in some cases primarily developed, to support the designer's work with hypotheses. They may help designers identify, compare, manipulate, or challenge potential solutions. Such *instruments of inquiry* can be mainly *semiotic*, e.g., in the form of templates, *material*, e.g., in the form of sketching materials, or a combination. Sometimes, these are relatively generic instruments, exemplified by e.g., Shneiderman's (2001) work on how advanced information visualisation can support creative work by enabling users to find, identify, filter, and discover patterns in large data sets, or by the use of schemata that help designers map the most salient features of a design space to get an overview of the design situation and see potential relations between components aspects of it (Biskjaer, Dalsgaard, & Halskov, 2014). At other times, designers have to develop custom instruments for specific design projects that present them with novel challenges.

Figure 4. Rendering of the projected museum building.

As an example from another collaboration with the architectural firm Bjarke Ingels Group, we worked on a proposal to build a new museum of modern art in Warsaw (see Figure 4). Our role was to develop media architectural components for the museum, described in more depth in Dalsgaard, Halskov, and Nielsen (2008). The initial design brief was very open, namely to develop interactive components for the proposed museum building. As a means for mapping the design space, getting an overview of the opportunities, and discussing potential installations with the architectural firm, we employed a so-called Design Space Schema (Biskjaer, Dalsgaard, & Halskov, 2014). The schema outlined the main design aspects to consider, e.g., location, users, situation, input and output technologies, and content, as well as the various options for each aspect. For example, the potential locations could be the façade, the arrival area, hallways, exhibition spaces, and the potential input technologies could be camera-tracking, sensor data, input from mobile devices, etc. (see Figure 5). Seen as an *instrument of inquiry,* the design space schema was an abstract description of the opportunity space that we as designers operated within. The schema thus enabled and supported *conception* by offering the design team a quick way to consider combinations of specific options, such as looking at how different combinations of interface materials and forms could be employed in different locations and situations to support different types of interaction and content.

Externalisation

Instruments of inquiry enable and support ***externalisation****, by which designers can make imagined design solutions part of the world and allow them to manipulate, evaluate, and develop them in more detail and complexity. In this way, instruments of inquiry can extend our capacities by offloading cognition into external representations and forms, and by playing to our cognitive strengths and potentials.*

In *designerly inquiry*, we often rely upon physical materials as a medium for either exploring potential expressions, as the final medium of expression, or both. Physical *Instruments of inquiry* are often the easiest to observe and lend themselves well to scrutiny. The sketches, models, mock-ups, and prototypes that designers use when exploring the potential forms of a product provide a good example of this. These provisional forms are more than just ways of representing already formed design concepts, they are a crucial part of the creative work: they serve as an extension

Material	Form	Combination	Location	Situation	Interaction sensing	Interaction style	Format	Content
Water Electricity Air	Tile Dot Tube Wire	Matrix Line	Plaza Metro Parking lot Entrance Exhibition space Corridor Wall Floor Ceiling	Passing by Arrival Resting Self-expression Departure Playing Observing Exploring Sharing	Autonomous Passive Active	Movement Gesture Touch Input device	Film Image Text	Information Ornamentation Guidance Data visualisaion Reflection

Figure 5. A design space schema for the museum project.

or distribution of imagination and allow for designers to bring the world into the process and enter into reflective conversations to explore potential futures. This understanding of *designerly inquiry* is akin to the theory of distributed cognition, developed by Hutchins (1995), which holds that cognitive processes occur beyond the individual and can be distributed across people and technologies. A central tenet in distributed cognition is that externalisation can enhance our capabilities because it helps us overcome our limited abilities to grasp and manipulate complex constructs by offloading cognition to our environment through externalisations. In *How Designers Work*, Gedenryd (1998) builds upon both Dewey and Hutchins to develop the term interactive cognition to denote the distributed process of *designerly inquiry*, and examines how designers employ resources in the design situation to augment imagination:

> Quite simply, these techniques re-create the various parts of this situation that do not yet exist. To make interactive cognition work well, the designer has to create her own working materials; before the world can become a part of cognition, the designer has to create it… They serve to make the world a part of cognition. (p. 157)

Competent designers are often characterised by their ability to bring the resources and tools in the design situation to bear on a problem. Sometimes, externalisations themselves become *instruments of inquiry*. A common example of this would be prototypes, which are both manifestations of specific concepts and also instruments that help designers interact with and reflect upon aspects of potential futures.

To offer an example from our work, one of the designs from the aforementioned Museum case was to employ thermo-chromatic concrete, namely concrete that can change colour when heated, allowing it to function as a display. This was a novel display technology, and we had little reference material to rely upon regarding what such a display would look like. In addition to experimenting with physical samples, we also carried out a series of sketches using off-the-shelf photo manipulation software. This enabled us to create externalisations that enabled us to examine the potentials and limitations of thermo-chromatic concrete. We employed filters to simulate the appearance of well-known visuals (such as the Mona Lisa, see Figure 6), and by creating a simple slideshow, we could fade between images and simulate the slowly changing thermo-chromatic concrete.

Knowing-through-Action

Instruments of inquiry enable and support ***knowing-through-action****, in which new knowledge is generated through acting with an instrument. A particular variant of this is transinstrumentality, in which designers can start working on a problem without knowing exactly where they are heading, and trust their mastery and use of instruments to help them build new understandings along the way.*

In a pragmatic understanding of inquiry, thinking and doing are reciprocal and closely intertwined, to the extent that it can be hard to makes sense of one without the other. Designers form ideas and hypotheses in response to the design situation, and they continuously act upon them to try them out, refine them, and transform them to move forward in the design process. These actions, in turn, inform, challenge, and transform the ideas and hypotheses. This can be considered a form of epistemic action, defined as: "… actions performed to uncover information that is hidden or hard to compute mentally" (Kirsch & Maglio, 1994, p. 513). *Instruments of inquiry* can scaffold this process by allowing designers to interact with aspects of the design situation in a low-risk, virtual environment. Virtual, in this case, does not refer to digital virtuality (although digital simulation tools can be very effective in this regard), but to the near-real, which can be achieved through analogue means as well as digital ones. When designers master *instruments of inquiry* such as sketching tools, they can rapidly move through iterations of thinking and doing in which they both expand their own understanding of the design situation and develop the design concept. Knowing-through-action is related to Schön's (1983) notions of knowing-in-action and reflection-in-action, which also builds on Deweyan pragmatism, however with distinct differences: knowing-in-action refers to the pre-established expertise and knowledge unfold in skilled practitioners' actions, often tacitly; and reflection-in-action concerns the practitioner thinking about the action process that (s)he is engaged in, whereas knowing-through-action entails the construction of new knowledge generated through action. Instruments can become an ingrained part of a designer's practice, allowing them to start working without necessarily having formed an exact idea about which the direction the process will take. Most people will recognise this from our use of language (which, incidentally, Dewey called 'the tool of tools'); we can start talking without knowing exactly what we want to say, and still end up saying something meaningful in the situation. Kirkeby (1994) calls this process '*translocutionarity*', i.e., *through language*. In design practice, we can observe analogous processes of what we might call *transinstrumentality*, in which competent designers start working with well-known instruments without knowing exactly where they are going and what they want to achieve, and yet as the interaction between designer, instrument and situation unfolds, they end up producing something meaningful, which advances the design process.

Figure 6. A series of sketches simulating the use of thermo-chromatic concrete in the museum project.

To offer an example, I return to the Expo Pavilion case introduced in the *Perception* section above. One of the major design challenges was to understand what type of content would be meaningful and comprehensible on this media façade. Even though we had a clear concept in mind—a 3600-pixel elongated media façade with interactive content—it was nearly impossible to get a mental image of how different types of content might appear on this radically novel display. We quickly realised that off-the-shelf software could only help us simulate static images; however, this was not adequate for us to examine, evaluate and experiment with the potentials of this display. For this reason, we developed the Pixel Tool, a Flash-based application that could simulate different forms of content on a section of the display, while also allowing us to modify parameters that would influence the appearance of the display, e.g., the time of day, cloud cover, etc. (see Figure 7). The Pixel Tool thus enabled us to perform quick iterations of ***knowing-through-action*** in which different parameters and content forms could be examined. It allowed us to work transinstrumentally by starting with simple shapes and forms, and then adding and adjusting parameters such as the amount of sunlight in relation to the light and colour output of the pixels, transitions between content elements, flow of visuals across the façade, and so on., allowing us to explore potential concepts in a way that would have been nearly impossible to examine by our imagination alone.

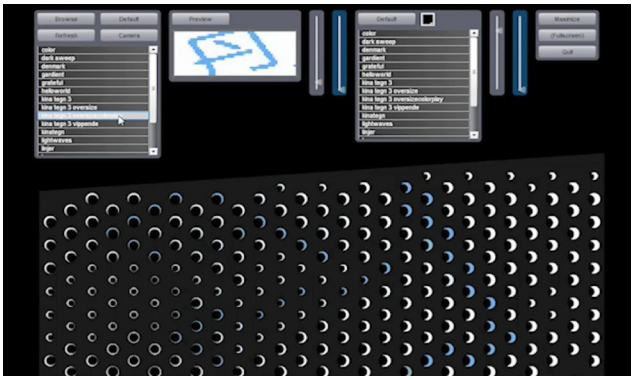

Figure 7. The Pixel Tool allows designers to adjust a range of parameters for simulating content on the pavilion façade.

Mediation: Connecting to Other Entities in the Design Situation

*Instruments of inquiry enable and support **mediation** between actors and artefacts in a design situation, allowing them to coordinate actions, exchange and synthesise insights and perspectives, and establish stable shared points of reference.*

Implicitly and explicitly, *instruments of inquiry* mediate relations to other entities in the design situation. Recalling the Deweyan definition, a situation is composed of not just the subject (or designer, in this context) and the instruments in use, but also of other people, artefacts and the physical and socio-cultural context. Resolving a design problem means transforming the situation as a whole, and it therefore goes beyond the introduction of a new piece of technology (although this may play a major part in the transformation). Some instruments simulate relations between entities in the design situation, e.g., personas (Cooper, 1999) for simulating potential users, architectural renderings for simulating the spatial context, and pre-existing data-sets for simulating input from connected it systems. *Instruments of inquiry* can, however, also more directly mediate relations between the constituents of the design situation. Roschelle (1992) has examined these forms of instruments in a Deweyan perspective, stating that "A *collaborative technology* can be defined in reference to a more encompassing and powerful goal: the communal way of seeing, acting, and knowing. A collaborative technology is a tool that enables individuals to jointly engage in active production of shared knowledge" (p. 40). *Instruments of inquiry* can support design in a range of ways, for instance by serving as tools for communication among stakeholders and designers through shared representations, e.g., renderings of potential products; by making design concepts understandable and open to feedback from other parties, e.g., mock-ups that offer hands-on experiences for end-users in a design project (Ehn & Kyng, 1991); by offering collaborative features for multiple stakeholders to co-create, as do web-based services such as Google Docs; and by supporting joint inquiry and exploration of a design space, as do e.g., Building Information Models in architecture. As examined in more depth in the field of Cultural-Historical Activity Theory 4, many instruments of this nature are themselves manifestations of specific relations and working arrangements, and thus frame and guide inquiry in specific ways.

To offer an example, I again turn to the Expo Pavilion. The two main collaborators in the project were our interaction design research lab and the Architectural Firm. While the researchers in the interaction design lab were familiar with using 3D models to experiment with different forms of interaction, the architects were not. However, the architects, were familiar with using physical scale models as *instruments of inquiry.* To support ***mediation*** between these two involved parties, we developed a *Mixed Reality Model*, comprised of a precise 1:100 scale model of the Pavilion, onto which we employed 3D projection to project the virtual 3D model of the pixel configuration (see Figure 8). This form, which combined modes of representation that each group was familiar with, enabled us to jointly examine different scenarios and forms of content through an advanced instrument that played to the strengths of both parties.

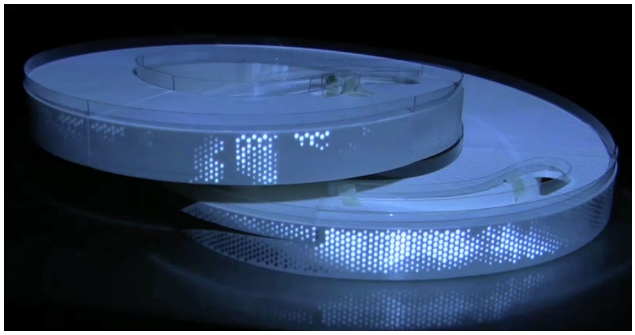

Figure 8. The Mixed Reality Model combines physical and virtual models of the expo pavilion.

Summary: *The Five Qualities as Interconnected Components of the Framework*

The five qualities discussed here offer a framework that underscores the explorative and experimental nature of design and the role that instruments play in *designerly inquiry*. While these qualities may also apply to instruments in other forms of inquiry, I focus here on the specific role they play in design. The five qualities can function on different levels of abstraction: they can account for small-scale operations related to specific design problems, e.g., sketching out the details of a component of a system, as well as to over-arching issues, e.g., discussing and reframing the general objectives of a project. As stated, the qualities are often intertwined in practice. The ways in which instruments guide our perception towards specific design problem affects the hypotheses we conceive for addressing them, the externalisation of specific dimensions of a design idea influence how we can build up new knowledge through acting on it, and so on. In the above examples, I have focused on how each instrument supported a specific quality, but it should be clear to the reader that they each possess multiple qualities for supporting designerly inquiry. For example, in the Expo Pavilion case, the 3D Model, the Pixel Tool, and the Mixed Reality Model were all externalisations; they each supported different modes of perception and conception; they all afforded knowing-through-action, and they were all mediations in different parts of the project.

Discussion: *Mastering and Refining Existing Tools, and Developing New Tools to Support and Guide Design*

While designers rely on instruments that have become part of their repertoire (as per the above discussion of instruments and design competence), design projects often require designers to modify existing instruments, or to develop new ones. Many of most commonly used tools in design are adaptable in the sense that they can be employed in a variety of projects and modified to suit the specific demands of a given design situation. From the media architecture examples, this is the case for the sketching software and the design space schema, which can be employed in most design projects. From a pragmatist perspective, the popularity of many well-known instruments owes to the fact that they can be employed over and over. Therefore it is well worth the time and effort spent to master them and integrate them into a designer's repertoire. Another important aspect, underscored by the pragmatist perspective, is that instruments in their current form are the externalised results of past histories. They are shaped, developed, and refined over the course of time, and represent specific ways of working that have proven fruitful in the past. In addition to the use or modification of existing instruments, some design projects require, or benefit greatly from, the development of new instruments. The three instruments from the Expo Pavilion case exemplify a somewhat different approach to developing new instruments, in that none of them were prototypes of the future product. Rather, each of these instruments was developed as a means for simulating, exploring, and experimenting with design concepts. The need to develop new tools is more prevalent in some disciplines than in others. In emergent fields, such as those dealing with the development of digital products and services, the need for novel instruments may be more pronounced, as seen in the media architecture cases in this paper. However, the ongoing development of novel *instruments of inquiry* occurs in most fields to some extent.

If we accept the pragmatist premise that instruments are central in designerly inquiry, it follows that the mastery of instruments is an essential part of design competence. Indeed, Gedenryd (1998) has noted that the worst thing you can do to a competent designer is to tie their hands behind their back, ask them to sit in a chair, and solve a design problem by thinking it through without access to the instruments and the ability to manifest design ideas and concepts that are normally at their disposal, because this bereaves them of a large part of their competence. Since instruments guide how we perceive problems and constrain the space of potential solutions, an important aspect of developing design competence is to understand how specific instruments will help them identify specific problems in a situation, and of seeing specific solutions to said problems. In a pragmatist perspective, it is not inherently problematic that a given instrument will steer the design process towards a specific goal, for this is in many cases exactly what a designer may want. Rather, this highlights that designers must be aware of how their tools lead them towards certain outcomes. Mastering an instrument is therefore both a question of developing the skills to use it to reach a desired outcome and of understanding its role, potentials, and limitations in a given project. While I have focused in this paper on pragmatism, it is worthwhile to supplement this perspective with insights from Cultural-Historical Activity Theory on how the mastery of an instruments leads it to become *internalised* into the designers mode of thinking and acting (Bødker, 1990). Paradoxically, another part of this competence comes from being able to distance oneself from an instrument and consider how different approaches could lead to one to see different solutions, or perhaps even reframe the design problem. As a consequence, competent and reflective designers should be familiar with a range of instruments, and should know how, when, and why to use them.

Different Perspectives on Instruments in Design Research and Their Effect in Practice

The conceptual frameworks that underpin our understanding of design have implications in practice, much in the same way that different *instruments of inquiry* have implications for how designers understand and approach design problems. Bødker and Kammersgaard (1984) present a similar argument in their examination of different perspectives on interaction styles in Human-Computer Interaction, showing how different perspectives on IT have profound implications for the outcome of an IT design process. The pragmatist perspective offered in this paper highlights the explorative and experimental characteristics of *designerly inquiry.* As such it differs from other perspectives,

e.g., the so-called *economic principle of prototyping*, defined by Lim, Stolterman, and Tenenberg (2008) in their clear and systematic analysis of the characteristics of prototypes: "the best prototype is one that, in the simplest and most efficient way, makes the possibilities and limitations of a design idea visible and measurable" (p. 7:3). This perspective invites a more rationalistic approach, in which the role of the prototype is less a means for understanding and experimenting with design concepts through the making and use than with evaluating criteria defined by the designer before the prototype is made. A third perspective is the more widespread understanding of design instruments as tools for carrying out intended actions by a designer, as augmentations of action capabilities. A fourth perspective, which is in many respects more similar to the one offered here, is the Cultural-Historical Activity Theory perspective on tool as mediator between subject and object (Bertelsen, 2000). I do not consider the pragmatist perspective offered here to be an exhaustive account of tools in design. On the contrary, I see a need for more studies and articulations of the role of tools in design, especially ones that go beyond specific tools and offer over-arching frameworks. An interesting avenue for future research would be to better delineate these positions and establish dialogues between them.

If we consider the pragmatist perspective on instruments in *designerly inquiry* presented here, we see several implications. The primary aim is to add to the discourse on design regarding the role and nature of instruments as an integral part of creative design processes. Supported by the two media architecture cases, I also argue that it offers a coherent and theoretically well-founded framework for analysing specific design cases. Beyond this, the framework can be of value for design practitioners by offering a set of considerations to take into account when selecting, employing, adapting, and perhaps even developing instruments to fit specific design projects, and we are currently exploring this in practice. As per the above discussions of design competence, the framework points to topics that can be integrated into design education, a field that has already been strongly influenced through Schön's (1983) work on reflective practice. Finally, the framework also offers directions for developing new instruments that are specifically aimed at supporting *designerly inquiry*, such as simulation software or co-creation tools.

Conclusion

Given the prominent role that instruments play in design, it is somewhat surprising that there are few contributions that offer overarching frameworks to examine and explain how and why they work. In this paper, I have argued that such frameworks can be of value for developing both the theory and practice of design, and that pragmatism offers a well-suited foundation for understanding the integral part that instruments play in *designerly inquiry.* When brought to bear on design, the pragmatist perspective brings to the fore the explorative, creative, and experimental nature of *designerly inquiry*, which in turn has influenced our development and examination of the five qualities of *instruments of inquiry*, which enable and support *perception*, revealing facets of a design situation that would otherwise be hidden, while obscuring other facets; *conception*, helping designers understand and articulate the problems they face, develop hypotheses about how they might address these problems, and examine and revise these hypotheses; *externalization*, by which designers can make imagined design solutions part of the world and allow them to manipulate, evaluate, and develop them in more detail and complexity; *knowing-through-action*, in which new knowledge is generated through acting with an instrument; and *mediation* between actors and artefacts in a design situation, allowing them to coordinate actions, exchange and synthesise insights and perspectives, and establish stable shared points of reference.

The *Instruments of Inquiry* perspective emphasises how tools in design allow for new ways of experiencing the world; they expand what we can understand and achieve; they help us experiment with potential futures and build knowledge through action; and they guide us towards specific solutions to design problems. As a consequence, a crucial dimension of design competence is to master specific types of instruments, and to be knowledgeable and reflective about their potentials, limitations, and place in a larger design situation.

Our aspiration is that this perspective can enrich the discourse of design by complementing and expanding the current understandings of instruments in interaction design and design creativity, and form a basis for further developments in the field. Our ongoing and future avenues of research to advance this agenda lie in a) employing the framework pro-actively to support and examine how designers select, modify, and develop *instruments of inquiry* in design practice, b) analysing how the five qualities are at play in existing, useful instruments in creative design, and c) using them to support the development of novel *instruments of inquiry*.

While our objective here has been to examine how a pragmatist perspective on instruments can add to the field of design, it can also be seen as a way of examining, challenging, and expanding upon pragmatism through the development of the notions of *designerly inquiry* and *instruments of inquiry*. The value of theories, according to pragmatism, depends upon how well they help us understand and act in a world characterised by emergence and change. This also applies to foundational theories such as pragmatism itself, which must also be revisited, and potentially revised and expanded upon, in order to remain useful. The experiences from employing the pragmatist perspective to frame and analyse instruments in design practice here echoes statements from related work that it is indeed a well-suited framework for adding to our understanding of design. There is much potential in establishing dialogues between pragmatism and other theoretical positions in order to further develop the theoretical foundation for design.

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Endnote

1. This section draws primarily on Dewey and Southern Illinois University (1969); Dewey and Boydston (1980, 1981); Dewey (1934, 1938).

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