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Learning from Learning - Design-Based Research Practices in Child-Computer Interaction

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ABSTRACT

Inspired by the use of design-based research (DBR) in the learning sciences, in this paper, we discuss the promise of applying DBR in Child-Computer Interaction (CCI). As much research in CCI is related to learning interventions and educational contexts, we believe that DBR can be highly relevant for CCI, but that it has not yet reached its full potential in the field. We argue that DBR as a research approach can help mature the field, by explicitly grounding research design and interventions in theory, foster better impact beyond project completion, and bridge theory and practice through clarified knowledge contributions. Grounded in the characteristics of DBR, and based on a scoping review, this paper provides a timely snapshot of DBR literature, practices and research contributions in CCI research. Based on this, we will discuss further implications and opportunities of DBR in the CCI field.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**.

KEYWORDS

Design-based research; HCI; learning; child-computer interaction; CCI

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1 INTRODUCTION

In recent years, several research papers (e.g. [29, 83, 85, 102, 128, 176]), and workshops at the Interaction Design and Children (IDC) conference [9, 28, 126] have brought up the need for improving knowledge and theory development within Child-Computer Interaction (CCI). For instance, in the editorial to a special issue of International Journal of Child-Computer Interaction (IJCCI) focusing on review articles, Giannakos et al. state that "future work needs to consider the development of models, theories and guidelines that could guide the design of interactive artefacts for children beyond particular artefacts" [83, p. 7]. One of the suggestions has been that working with Intermediate-Level Knowledge, placed in-between theories and the study of particular cases might be a way forward [29, 101]. Another way to enrich the field is to bring in inspiration from related fields. For instance, Iivari and Kuutti, with inspiration from HCI and design research, suggest introducing more concepts and ideas from critical design into CCI [102]. In addition to these examples, there are many other possibilities to explore and a lot more to do when it comes to how we can work with research practice and knowledge production within CCI in a disciplined manner [83, 85, 176].

One of the most common domains for research within CCI is various forms of learning interventions and design for learning [74, 84, 99]. Indeed, out of the nine full paper sessions listed in the 2022 IDC proceedings, four contain learning in their title, one computational thinking & makers, and one is about computational literacy [1]. In the 2023 proceedings, two out of nine sessions are about STEAM tools for learning and one about multisensory learning [2]. Since learning sciences is a big research field, one can imagine that there are possibilities for CCI to learn from, and be inspired by, the learning sciences when working on, and developing knowledge from, research carried out in a learning context. A recent literature review by Eriksson et al. on the use of learning theory within CCI [74], shows that the role of theories is rather scattered and suggest that "when addressing learning, CCI research needs to provide explicit theoretical grounding for aspects of learning in both the research design and result" [74, p. 60]. In line with the above-mentioned need for improving knowledge and theory development within CCI, a question worth investigating is if there is something to learn from the learning sciences about how to do research, in particular related to learning interventions, that can contribute to improving how we do research in CCI in ways that can lead to increased knowledge production?

A large share of the learning focused papers within CCI describe research where some kind of artefact has been developed and tested with children, often in a school context. This goes in line with the prevailing practice in HCI (and its subfield CCI), where the dominating approach to the construction of new knowledge is to develop innovative artefacts (based on information technology) and to then test and evaluate them empirically with the goal of extending our knowledge of the interplay between humans (children) and information technology [101]. Research within HCI with a large element of design and development of innovative artefacts, is often guided by e.g., ideas of Research through Design (RtD)

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[43, 66, 76, 79, 81, 110, 205, 206] or Action Research [92, 93]. As described by Zimmerman and Forlizzi, RtD can be seen as one way to handle the interesting challenge in HCI that the artefact comes before theory, rather than that theory spurs the creation of new innovative artefacts [204]. Well-known examples illustrating this phenomenon, are the mouse and direct manipulation, which were developed long before studies and theory existed that could explain them as good designs [204]. Action research has a strong focus on doing research together with a community, taking action to address a problem or a challenge, and to, through an iterative process, develop scholarly knowledge [94].

Bringing design and the development of innovative artefacts into research and trying to find appropriate methods and principles for how to combine the sometimes-conflicting views of science and design is a matter that has also been identified in the learning sciences where researchers recognized a need to identify other ways of doing research than the dominating controlled experimental studies [45]. They wanted to develop research approaches that were closer to real-world practice but could still contribute to theoretical understanding and development in the field [45, 58]. Another underlying motivation was to develop methods that could contribute to changing the current state into a desired one rather than studying and drawing conclusions from the current (or past). This led to the development of what is now typically referred to as Design-Based Research (DBR) [20, 26, 45, 55, 58, 60, 132, 149, 174]. To distinguish it from e.g., similar approaches in HCI it is sometimes called Educational Design-Based Research. In DBR, the core approach to research is that interventions are designed and developed together with practitioners (i.e., teachers), and tested in real educational contexts (i.e., schools) [13], with the goal to not only make a practical contribution but also contribute to knowledge production [26]. With their common focus on iterative development of various kinds of artefacts that are applied and tested in real contexts many similarities can be observed between DBR, RtD and AR even if they are distinct approaches each backed by their own definitions and ideals.

Following that learning is such a big part of CCI and that DBR is a popular approach when working with applied research within the learning field, one could expect that there would exist numerous publications where the intersection of (educational) DBR and CCI/HCI are presented, discussed, and analyzed in various ways. However, we have only been able to find a limited number of such publications in the core CCI publication venues the Interaction Design and Children conference and the International Journal of Child-Computer Interaction (e.g., [9, 126]). On the other hand it is clear that DBR is being used within CCI. A search through the proceedings of the IDC conference yields that there are 25 papers that mention the notion "design-based research" and reference some DBR related source. As a comparison, the same search for "research through design" resulted in 10 hits [18, 29, 31, 32, 54, 77, 139, 140, 169, 194], while a search for "action research" gave 9 results [35, 78, 134, 135, 143, 181, 182, 188, 189].

In summary, several authors have noted the need for developing theory and methodology within the CCI field where learning interventions is one of the most common domains for research and one research approach stemming from the learning sciences with a clear focus on knowledge production is DBR. Therefore, investigating the usefulness of DBR for CCI research appears to be a promising potential venue for further work. To investigate the status and use of DBR in CCI, we make a scoping review focused on two research questions:

- **RQ1:** What are the DBR practices (context, methods, innovation, iterations, partnership) in CCI?
- **RQ2:** What are the types of contributions of DBR based research in CCI?

The result is a current snapshot of the DBR research landscape in CCI. Our argument that CCI could gain from applying a DBR approach is not new. As mentioned above, previous efforts have raised similar concerns [9, 126], however, here we try to clarify the characteristics of DBR while also illustrating its current use in CCI.

The rest of this paper is organized as follows: the next section presents DBR, including some findings from reviews of the field. This is followed by a description of how the scoping review of DBR was carried out and the results from the review. Based on the review, we then discuss further implications and opportunities of DBR in the CCI field.

2 BACKGROUND: DESIGN-BASED RESEARCH

Design-Based Research (DBR) is an established approach for carrying out educational research, first introduced near the end of the 20th century [13]. Early papers describing the concept, which is also known as "design-research" (e.g. [152]), "development research" (e.g. [183]), and "design experiments" (e.g. [55]), include those by Brown [45] and Collins [58]. Sometimes the term educational design-based research is used to distinguish it from research in e.g., human-computer interaction [20]. While a lot of educational research is focused on studying the current educational practice as it *is*, or perhaps *was*, the focus of design-based research is how education *could*, or *should*, be carried out [20]. Educational researchers have argued that controlled experiments in classroom settings are neither realistic nor generalizable and propose the design-based approach as an alternative that better meets the needs of designers and users when developing tools for use in formal classroom settings [45, 60, 168]. Further, the use of DBR can be a possibility to bridge the gap between educational practice and theory, since its goals are to both advance domain-specific theories about learning and design and develop the tools used to support the learning process [20].

Educational design-based research can in short be described as research where the design of new educational materials, such as information technology, classroom activities or in-job training for teachers, is a central part [20]. Plomp defined DBR as

> the systematic study of designing, developing and evaluating educational interventions, – such as programs, teaching-learning strategies and materials, products and systems – as solutions to such problems, which also aims at advancing our knowledge about the characteristics of these interventions and the processes to design and develop them. [149, p. 9]

A review paper by Anderson and Shattuck [13] presents DBR as being defined by the following key characteristics:

- *Being Situated in a Real Educational Context.* This ensures that the results are valid at least for this context.
- *Focusing on the Design and Testing of a Significant Intervention.* The design, development, and testing of an intervention is at the core of DBR.
- *Using Mixed Methods.* Typically, several research methods are applied in a study. DBR does not limit research to certain methods only.
- *Involving Multiple Iterations.* DBR is carried out in an iterative process with many refinements to the design.
- *Involving a Collaborative Partnership Between Researchers and Practitioners.* Researchers and practitioners (e.g., educators) work closely together to create and carry out the research project.
- *Evolution of Design Principles.* The goal of the design process should be to develop re-usable design knowledge.

Hoadley and Campos present a high-level process for DBR consisting of four phases: Grounding, Conjecturing, Iterating, and Reflecting [95]:

- The *Grounding* phase is about finding a gap or problem to study with a real-world intervention. It further involves studying the current situation and existing theory and defining the bounds of the project [95].
- *Conjecturing* is about defining an initial set of high-level conjectures intended to guide the development and testing of a design. This phase often follows the conjecture mapping approach suggested by Sandoval [161] and deals with describing how certain design choices can lead to specific mediating processes that in turn will lead to specific hypothesized outcomes for learners [95].
- In the *Iterating* phase a series of designs are developed and tested. The designs are realizations of the ideas from the previous phases and the experiences from each iteration are used as basis for the next one, e.g., in the form of refined conjectures [95].
- The last phase, *Reflecting*, involves analyzing all the data collected during the process. The goal is to be able to identify which actions or circumstances that have led to changes in the studied environment and how [95].

This is similar to other descriptions of the DBR process e.g. [75, 131, 132], in that DBR processes are not linear, but rather consists of multiple cycles which is conducted 1) through three core phases in a flexible, iterative structure: Analysis and Exploration, Design and Construction, and Evaluation and Reflection; 2) through a dual focus on theory and practice leading to Theoretical Understanding and Maturing Intervention; through 3) planning for Implementation and Spread of the results by having interaction with and integration of practice and stakeholders present from the outset and increasing over time.

The end goal of the reflecting phase, as described in DBR, is to create knowledge that go beyond the particular intervention. This is a recurring theme in texts on design-based research, i.e., that the purpose of DBR is to further knowledge and theory and that the interventions created within DBR need to go beyond being product development for better learning environments, see for example [26, 55].

The knowledge produced by DBR projects can take many forms, but in this paper we focus mainly on the six categories described by Hoadley and Campos [95]. The six categories suggested by Hoadley and Campos are:

- *Domain Theories*, generalizations of a specific piece of a high-level, hypothesized learning theory. This can for example be how online environments influence learning. DBR can lead to domain theories related to the context of the intervention or the outcomes allowed by the design [72, 95].
- *Design Principles or Patterns* are common forms of (intermediate-level) knowledge within HCI (and CCI) [101]. While domain theories can be used to describe a phenomenon, design principles and patterns have a more prescriptive nature. That is, they can be used as guidance for how to design an intervention in a given context. However, they will always need to be adapted to the local circumstances [95].
- *Design Processes* contain the prescriptive procedural knowledge that forms a particular methodology for achieving a type of design, including the needed expertise and the roles of the persons involved in the process [72, 95].
- *Ontological Innovations* can shortly be described as new explanatory constructs, categories or taxonomies aimed at explaining how something works. They are often the result of that the iterative cycles of building and testing leads to that researchers encounter situations that challenge current frameworks [68, 95].
- *New Hypotheses* come up when design leads to questions rather than answers [45]. The questions can lead to new hypothesis that can be the focus of future research [95].
- *Design Researcher Transformative Learning* is about how the immersive nature of DBR may affect how researchers experience design knowledge [95]. Such transformative learning describes a series of "a-ha moments" that make it possible for researchers involved in DBR to develop new conceptualizations of "how they position themselves as actors within the situation they are exploring" [104, p. 10]. This is in line with Gaver et al., who ask us to also appreciate the insights and learning to be found in more unpredictable research journeys [82]. They call this emergence, which is typical in practice-based design research, as plans and understandings can change in response to experience with people, settings, ideas, and things. They call for emergency in practice-based design research to be embraced in research and reporting [82].

2.1 Perspectives on DBR

During recent years several literature reviews have been conducted with the aim of describing the field and investigating if it lives up to its promises. Anderson and Shattuck [13] concluded that even though most "interventions have resulted in improved outcomes or student attitudes (. . .) it is unclear if the results achieved are meeting the challenge of promoting widespread adoption of the tested intervention" [13, p. 24]. Zheng [201] described how most of the DBR studies are focused on "designing, developing, and re-designing learning environments through interventions" [201,

p. 399], but often fail to describe how the interventions have been revised.

Recently, Tinoca et al. [175] illustrate the recognition of DBR as a methodological approach to bridge the gap between theory and practice. Similar to previous reviews [13, 201], the most prevalent outcome shows the potential of DBR to foster improved learning for students, across a wide variety of domains, even if there is a clear dominance for science-related learning areas [175]. It further shows that technological interventions seem to be the most referenced topic in the analyzed studies, within curriculum/pedagogy and assessment practices context and goals, particularly in natural, social, and technological science. The theoretical framework tends to be grounded in the specific learning theories of the main subject. It should also be noted that most of the included studies do not give a thorough report on their DBR design. Even though supporting references to DBR pioneers are frequent (e.g., [13, 26, 61, 132, 174]), detailed explanations of DBR design, such as the type and duration of interventions, data collection methods, and end of cycle reports, are often missing. It is also common to find studies reporting only one of the intervention cycles and missing a larger scope of the bigger research design being developed. Many studies also do not report on the obstacles and limitations they have faced, contrary to what is recommended in DBR design [187], or contribute with recommendations for the improvement of the DBR methodology employed.

Based on their results, Tinoca et al. recommend for future research in the DBR field the need of a more extensive and descriptive approach for the presentation of the design of the intervention planned and implemented, including listing each cycle/iteration and its full documentation (time, commitment, contingencies, activities, data collection, and analysis). Also, the discussion about how results can be emphasized and generalized (since the majority is local), and its impact, is another suggestion for future studies that should be supported by valid and reliable methods and evidence, allowing the replication of research at a larger scale.

3 METHOD

The goal of our scoping review is to shed light on the diverse adoption of design-based research in the CCI research landscape. This means that we aim to provide a starting point that supports researchers in building an understanding of the ways that DBR in CCI is practiced and reported and what the different research types contribute. By integrating the wide variety of DBR approaches of the CCI community in our analysis, we aim to provide a meaningful way of understanding DBR in CCI. This section describes the methodology we followed in our scoping review, including how records were identified, screened, and assessed to make up our final corpus. Following the increasing trend of using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statements [138] for conducting reviews in HCI [170], we applied an adapted PRISMA statement for scoping reviews [177], depicted in Figure 1. We also describe how we conducted our analysis on the final corpus. In this paper, we provide a snapshot of the research landscape in the field, which we conceived as a scoping review [16, 116, 177]. As such, the paper sets out to map a certain area of academic interest, to "clarify a complex concept and refine

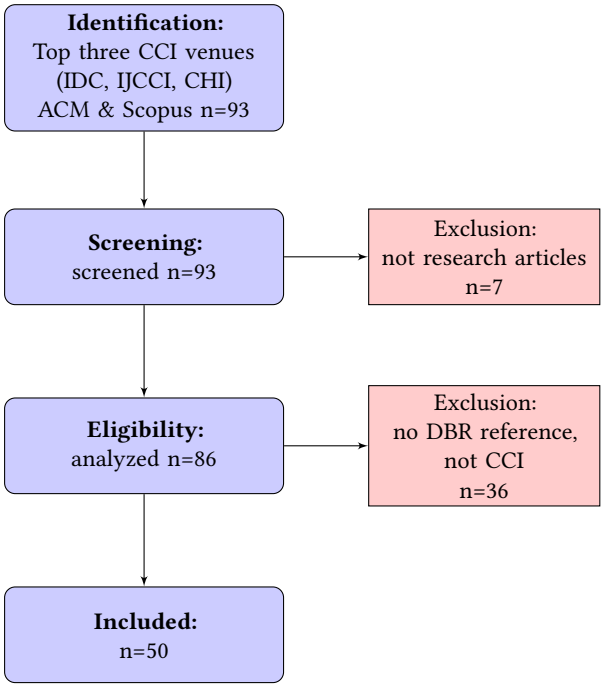

Figure 1: Adapted PRISMA flow diagram representing the selection and refinement process in our scoping review, from the identification of 93 records, to screening eligible papers and arriving at our final corpus of 50 papers. For each of the stages where papers were excluded (identification, screening, and eligibility) we further present the total of excluded records.

subsequent research inquiries" [116]. This review's goal is not a comprehensive overview; instead, it showcases a focused, specific snapshot of the current landscape of DBR research practices within CCI and beyond to make sense of current trends and patterns.

3.1 Identification

To investigate how DBR is applied in Child-computer interaction (CCI) research we have conducted a scoping review in three of the CCI community's leading venues: the Interaction Design and Children (IDC) conference, the International Journal of Child-Computer Interaction (IJCCI) and the Human Factors in Computing Systems (CHI) conference. The review is limited by only including three publication venues, and limited by the search query itself. As such, we make no claims to cover the whole CCI field.

In order to explore the state of the art of DBR practices in the field of CCI, we used the ACM Digital Library (DL) for IDC and CHI, and Scopus to collect publications in IJCCI. Similar to DiSalvo et al. that used a single search term ("sustainable HCI") in their review [67], our review is also limited to the single search term: "design-based research", that can be mentioned anywhere in the paper, and in publications classified as article types. The search was undertaken in September 2023. The first step of our procedure led to an initial set of 93 papers (CHI n=24, IDC n=41, IJCCI n=28). Our

review followed an adaptation of the PRISMA statement [138, 177], structured in four main phases (see Figure 1).

3.2 Screening

All three authors screened the initial set of 93 papers. In this first screening we decided to exclude papers that had not undergone peer review or were not classified as research articles in ACM or Scopus. Doctorial consortium papers are often part of a much larger project, and tend to make unclear descriptions about what is planned, what is being done, and what is done. In our corpus there are three doctorial consortium papers [50, 56, 64], all from IDC. It is clear that they apply DBR, although the methodological details and practices are not yet explicit, and have not been under peer-review, why we choose to exclude them. Another type of paper that was excluded here was a paper classified as editorial from IJCCI [6], and three papers classified as review articles from IJCCI [11, 30, 200], since these do not present any direct DBR practice.

3.3 Assessing Eligibility

All three authors went through all of the remaining 86 papers, and checked if the paper made any explicit reference to DBR literature. By DBR literature we mean papers or books that have design-based research, or some aspect of it, as their main topic, e.g., [20, 26, 45, 55, 58, 60, 132, 149, 174]. When looking for references to DBR literature we searched for a reference in relation to when 'design-based research' was mentioned in the text, and also reviewed the full list of references to see if there was something we missed. This led to the exclusion of 34 papers that made no reference to any DBR sources, IJCCI n=3 ([120, 122, 207]), IDC n=16 ([5, 36, 37, 41, 42, 46, 49, 53, 74, 98, 146, 155, 156, 178, 202, 203]), and CHI n=15 ([27, 80, 86, 97, 107, 109, 113, 118, 119, 151, 157, 158, 167, 180, 186]).

In the next step, we checked the papers for relation to CCI, which was primarily relevant for the CHI papers. This lead to the exclusion of two papers ([125, 191]).

After reviewing the 86 research papers based on the defined exclusion criteria (no explicit reference to DBR literature, no DBR practice, no peer-review, no relation to CCI), a total of 36 papers were excluded. The final corpus therefore consisted of 50 papers, 7 from CHI, 22 from IDC, and 21 from IJCCI, see overview in Table 1.

3.4 Analysis

The final corpus consisting of 50 papers was independently analysed by two of the authors. The code categories used in our analysis correspond to each of our research questions on *practices* and *type of contribution*. In our analysis, a consensus-based approach was applied [38]. In line with that, no inter-rater reliability has been calculated. First, three authors independently open coded [38] five of the papers of the final corpus to establish a shared understanding for the codes. As a second step of the analysis process, two of the authors coded all the remaining 45 papers. Note that both authors coded all the papers independently. If uncertainties arose, they were discussed with all authors throughout the process. Finally, a consolidating discussion session was additionally conducted, when the two authors had finished coding all of the papers. When coding the corpus for *practices*, we used the six key characteristics as defined by Anderson and Shattuck [13]: *Being Situated in a Real Educational Context*, *Focusing on the Design and Testing of a Significant Intervention*, *Using Mixed Methods*, *Involving Multiple Iterations*, *Involving a Collaborative Partnership Between Researchers and Practitioners*, *Evolution of Design Principles*. When coding the corpus for *type of contribution*, we used the six contribution types in DBR as defined by Hoadley and Campos: *Domain Theories, Design Principles or Patterns, Design Processes, Ontological Innovations, New Hypotheses*, and *Design Researcher Transformative Learning* [95]. An alternative framework of contribution types in HCI has been proposed by Wobbrock and Kientz (empirical, artifacts, methodological, theoretical, dataset, survey, and opinion) [192]. However, since we are trying to 'learn from learning' as the title of this paper says, we chose to use the contribution types as defined by Hoadley and Campos [95].

In addition, we did a quantitative analysis of the referenced DBR literature in order to see if there were some specific sources that appear to have had a special impact on the use of DBR in CCI.

4 RESULTS

In this section, we report on the results of our analysis. The remaining results section is organised in line with our research questions.

4.1 General overview

From the overview of the corpus in Table 1, we see that HCI research using DBR is more common in IDC than at CHI. This might be explained by that one of the most common domains for research within the IDC community is various forms of learning interventions [84]. In terms of papers per year, we also see that there is no increasing or decreasing trend in publishing CCI research using DBR at CHI and IDC. However, for IJCCI, the majority (75%) of the papers using DBR were published in the last five years.

4.2 DBR literature in CCI

An analysis of the references to DBR literature used in the corpus shows that the most common reference is to a paper by Barab and Squire [26] cited by 18 papers in the corpus. The second most cited paper, from a group calling themselves The Design-Based Research Collective [57], was found 14 times. A paper by Wang and Hannafin [187] was cited 8 times, closely followed by Collins et al. [60] cited 7 times. Three papers were cited four times [13, 45, 55], two papers three times [62, 163], and four papers two times [58, 111, 131, 161]. There were also 36 references to DBR literature cited only once [8, 12, 20, 21, 25, 33, 34, 39, 59, 63, 68, 70–73, 75, 96, 103, 106, 114, 129, 130, 133, 141, 144, 147, 148, 152, 153, 160, 162, 184, 190, 196, 199]. For an overview of the results from the analysis, see Table 2. A large majority of the papers make very brief descriptions of DBR. Typically, the papers use only a sentence or two to introduce and explain DBR. In many cases, the papers only mention that the work is a part of a design-based project and make a reference to some DBR source. Two exceptions are [69, 88] that to some extent explain what DBR is and motivates why it is used.

4.3 DBR practices in CCI

When coding the corpus for *practices*, we used the six key characteristics as defined by Anderson and Shattuck [13]: *Being Situated in a Real Educational Context*, *Focusing on the Design and Testing of a Significant Intervention*, *Using Mixed Methods*, *Involving Multiple*

Year	CHI	IDC	IJCCI
2008		Dervan et al.[65]	
2010		Wyeth and MacColl[193]	
2011	Howison et al.[100]	Tseng et al.[179]	
2012	Govaerts et al.[89]	Charoenying et al.[51] Blikstein et al.[40]	
2013		Shimoda et al.[168] Abrahamson[3]	
2014		Yip et al.[197]	Maertens et al.[122] Abrahamson[4]
2015		Chase and Abrahamson[52]	Sylla et al.[172]
2016	Yip et al.[198]	Hansen et al.[91]	
2017	Malinverni et al.[124]	McBeath et al.[127] Lee et al.[115]	
2018		Ribeiro et al.[154] Apostolellis et al.[14] Yiannoutsou et al.[195] Mills et al.[136]	Kelly et al.[105] Schaper et al.[164] Kynigos and Yiannoutsou[112]
2019	Madaio et al.[121]	Maldonado and Zekelman[123] Kim and Zimmerman[108] Axelrod and Kahn[19]	Mills et al.[137]
2020			Strawhacker et al.[171] Du and Salen Tekinbas[69]
2021	Payne et al.[145] Scheepmaker et al.[166]	Grizioti and Kynigos[90] Rötkönen et al.[159]	Aurava et al.[17] Celepkolu et al.[48] Sysoev et al.[173] Litts et al.[117] Akdeniz and Özdinç[10] Vartiainen et al.[185] Bar-El and Worsley[22]
2022		Brady et al.[44]	Agesilaou and Kyza[7] Schaper et al.[165] Arastoopour Irgens et al.[15]
2023			Odgaard[142] Goagoses et al.[87] Caiola et al.[47]

Table 1: Overview of the final corpus with n=50 included publications, n=7 from CHI, n=22 from IDC, and n=21 from IJCCI.

Iterations, *Involving a Collaborative Partnership Between Researchers and Practitioners*, *Evolution of Design Principles*.

4.3.1 Being Situated in a Real Educational Context. All papers report from research in a relevant educational context, either in formal, informal, or non-formal learning contexts. An exception is [3], who make a meta-analysis on twenty years of experience from DBR projects and does not provide methodological details for each of the studies. The most common type of context in the corpus is in formal learning (e.g. school). While the physical context might not be directly related to learning or elaborated on in the papers (e.g. church [198], nature [47], or a private room in a school [100]), the social settings and the participants mindset (e.g. due to recruitment from school, after-school activity or similar) still points to that the research is undertaken in a real educational context as defined in DBR.

4.3.2 Design and Testing of a Significant Intervention. Almost all papers presented an intervention (n=48). An example from IDC is Tseng et al. who focus on Mechanix, an interactive display for children to create, record, view, and test systems of tangible simple machine components [179]. There were also two papers that did not present a specific intervention (n=2). In IDC, Abrahamson makes a retrospective analysis of his own pedagogical design projects over the past twenty years, he articulates and compares two distinct activity genres for grounding mathematical concepts [3]. In CHI Madaio et al. present results from a qualitative study (interviews) for the design of technology to scaffold low-literate parental support for children's literacy [121]. Most of the interventions were some kind of digital system except for a few exceptions, such as design sessions [121, 159, 198], curriculum [91], a new pedagogical approach [52], and maker activities and program [108, 115, 127].

All papers in IJCCI presented a type of an intervention. Similar to IDC and CHI, the interventions were ranging from being an

Author	Title	Citations
Barab and Squire [26]	Design-Based Research: Putting a Stake in the Ground	18
Collective [57]	Design-Based Research: An Emerging Paradigm for Educational Inquiry	14
Wang and Hannafin [187]	Design-based research and technology-enhanced learning environments	8
Collins et al. [60]	Design research: Theoretical and methodological issues	7
Cobb et al. [55]	Design Experiments in Educational Research	4
Brown [45]	Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings	4
Anderson and Shattuck [13]	Design-based research: A decade of progress in education research?	4
Sandoval and Bell [163]	Design-based research methods for studying learning in context: Introduction	3
Confrey [62]	The evolution of design studies as methodology	3
Collins [58]	Toward a Design Science of Education	2
Sandoval [161]	Conjecture Mapping: An Approach to Systematic Educational Design Research	2
McKenney and Reeves [131]	Educational design research	2
Kucirkova [111]	iRPD—A framework for guiding design-based research for iPad apps	2

Table 2: Overview of the most cited DBR literature in CCI.

educational program or pedagogical framework e.g. [4, 15, 165, 185], a course or a learning module [7, 23], or results from testing of a digital system as intervention e.g., in [10, 47, 69, 105, 112, 117, 164, 171, 172].

4.3.3 Using Mixed Methods. Most papers mixed several research methods (n=46). An example from IDC is Blikstein et al. who used pre-and post questionnaires, video observations, computer usage documented with screen-capture software, interviews, field notes, and design artifacts [40]. However, a mixed-method approach was rare. An example using a mixed methods approach from IDC is Shimoda et al. who used it to evaluate the Web of Inquiry as a means to help students learn about inquiry and discuss their thinking with peers and teachers [168]. The examples for mixed methods from IJCCI combined audio and video recording and interviews and/or observation techniques or field notes to understand the phenomenon being studied e.g. in [164, 172, 185].

Two papers from IDC do not report about mixing several methods, namely [51, 159]. Likewise, two papers from IJCCI [10, 69] do not mix several methods but derive their results from interviews only.

4.3.4 Involving Multiple Iterations. When coding the papers we looked for if a) the paper mention something involving several iterations but only describes one, or b) the paper describes several iterations in some sense. We found that not all papers report on iterations (n=15). This is typically due to that the specific study reported on in the paper only report from one round of a larger DBR project. An example of not mentioning multiple iterations from CHI is Madaio et al. who refer to DBR as an iterative, mixed-methods research approach based on [24, 70], however, they do not present any specific design or iterations. The aim of their paper is rather to highlight the situated knowledge surfaced through qualitative research providing findings about the beliefs, goals, and values of parents in several rural communities in Côte d'Ivoire and suggest design implications for family-based literacy technologies for low resource contexts [121]. A bit more elaborate is Arastoopour Irgens et al., who describe the design and implementation of a CML (critical machine learning) education program, in order to investigate how children develop machine learning knowledge grounded in social, ethical, and political orientations in a CML education program, and what computational practices children engage in when developing robots for social good in a CML education program [15]. Although they do not outline all the iterations in detail, they clearly position the reported study as the third iteration of an ongoing participatory design study. This is in line with Sylla et al., who state that the paper only report from the first intervention (out of three) which is a four-month evaluation of a digital manipulatives for playful learning system [172]. Although the project in full last for a period of three years and followed an iterative, cyclical process of designing, testing, and redesigning (referencing [26, 55]), but the iterations are not described as such in this paper [172]. This contrasts with for instance Bar-El and Worsley [22], who clearly outline the iterative design process through detailed conjuncture maps [161].

4.3.5 Involving a Collaborative Partnership Between Researchers and Practitioners. Two papers from CHI ([89, 198]), 11 papers from IDC, and 8 papers from IJCCI did not explicitly clarify any partnership between researchers and practitioners (total n=21). Consequently, most of the papers in the corpus did involve practitioners in a partnership. One example from CHI is Payne et al. who partnered with the organizational staff and instructors in a summer camp, and developed the danceON system to support distance learning and deployed it in two consecutive cohorts of a remote, two-week summer camp for young women of color [145]. An example from IDC is Dervan et al. who partnered with technical experts, educators, domain experts, garden staff and the student's themselves in the design and evaluation of a technologically enhanced, environmental peer-education project: a garden in a Multi-User Virtual Environment (MUVE) [65]. An example from IJCCI is Kelly et al.

who describe the teachers and the community leaders as their research team that serve as facilitators and active participants in their design-based research process [105].

4.4 DBR knowledge contribution types in CCI

We found a few papers that do not make an explicit DBR theory contribution (n=3). These are not full papers, but a poster [65], work-in-progress[154], and extended abstract [89]. One example from CHI is Govaerts et al. who present the Student Activity Meter that visualizes learner actions, with four design iterations and results of both quantitative and qualitative evaluation studies in real-world settings that assess the usability, use and usefulness of different visualizations [89]. The lack of theoretical contribution might be due to the paper type (extended abstract), and the focus on usability and usefulness. Below, the various types of contributions as defined by Hoadley and Campos will be presented respectively: *Domain Theories, Design Principles or Patterns, Design Processes, Ontological Innovations, New Hypotheses*, and *Design Researcher Transformative Learning* [95].

4.4.1 Developing Domain Theories. The most common form of contribution is domain theories (n=16). From CHI, this includes e.g. Howison et al. who introduce an embodied-interaction instructional design, the Mathematical Imagery Trainer (MIT), for helping young students develop grounded understanding of proportional equivalence and describe their rationale for and implementation of the MIT through a design-based research approach and report on clinical interviews with students who engaged in problem-solving tasks with the MIT [100]. Another example from IDC is McBeath et al. who present three levels of conceptual tool use in maker activities, Familiarizing, Labeling, and Understanding, as important processes for both creating the design and explaining functional and conceptual components to others [127]. An example in IJCCI is by Sysoev et al. who designed animated elements in a programming app to support preschool children's language learning and evaluated children's representations of phonemes as a domain knowledge contribution.

4.4.2 Developing Design Principles or Patterns. This form of DBR contribution was found in n=13 papers. One example from CHI is Madaio et al. who identified implications for a culturally-responsive design of technology to scaffold low-literate parental support for children's literacy [121]. Another example from IDC is Yip et al. who present design implications regarding the affordances and constraints of social media platforms to support scientific inquiry in non-formal learning environments [197]. This form of DBR contribution was the most common in IJCCI papers. An example is by Kelly et al. who described design principles for the development of a social media app as a science learning environment [105].

4.4.3 Developing Design Processes. The number of papers in this category was n=6. The only example from CHI is Yip et al. who aim to understand how parent-child relationships in families shape co-design processes and how they are reshaped through co-design [198]. Another example from IDC is Rötkönen et al. who based on a case study provides an empirical foundation pointing at critical issues to be further investigated in distributed online co-design with children (such as multilingual design, social cohesion, facilitation roles, technologies, design breadcrumbs, negotiations and learner's pride) [159]. An example from IJCCI is about the roles of children in co-design process by Schaper et al. who analysed different viewpoints of adult stakeholders in order to find new strategies that balance power relations between adults and children to establish collective values, and enrich the range of roles of children in a design process [164].

4.4.4 Developing Ontological Innovations. Was found in n=10 papers. One example from CHI is Malinverni et al. who define a conceptual paradigm they call World-as-Support (WaS), which they compare with the Window-on-the-World (WoW) interaction paradigm by contrasting their assumptions and cultural values, as well as through a study of an application aimed at supporting the collaborative improvisation of site-specific narratives by children, and which led them to identify the affordances, strengths and weaknesses of these two paradigms [124]. Another example from IDC is e.g. Chase and Abrahamson who report on findings from a culminating study cycle in a DBR project that investigated the roots of algebraic cognition, and elaborates on the notion of reverse scaffolding and reports on a quasi-experimental research study that sought to evaluate this activity architecture [52]. In IJCCI, a study by Schaper et al. provide a framework for applying computational empowerment in formal educational contexts that contains a series of learning activities focusing on the technological aspects and societal impacts of machine learning and augmented reality technologies [165].

4.4.5 Developing New Hypotheses. We found no papers at CHI or in IJCCI in this category, and only one from IDC. Lee et al. present four design hypotheses for library Maker programs and spaces: (1) youths' ability to experience freedom in the space matters, (2) the physical space needs to be comfortable and configurable for the option of semiprivate groupings, (3) building Maker components by leveraging existing programs can be more successful than creating completely new programs, and (4) there is a need for visible "first-timer" areas and options to accommodate drop-in visitation [115].

4.4.6 Design Researcher Transformative Learning. Together with New Hypothesis, this is the least common form of DBR contribution in CCI (n=1). The only example from CHI is Scheepmaker et al. who designed a socio-material toolkit for teachers to continue to design technology with children after the researchers have left the field [166]. They are coming to the conclusion that a "stand-alone" material toolkit is not sufficient to enable teachers to evolve their practices around technology design with children, and they build upon the notion of infrastructures to re-think existing toolkit approaches by adding social components to their toolkit, and suggested further possibilities to create a socio-material infrastructure. We found no examples of this category from the IDC or IJCCI papers.

5 DISCUSSION

In this paper we present a scoping review regarding the use of DBR within CCI. This review was motivated by the observation that DBR can be useful for CCI, particularly in a learning context, and that it therefore is pertinent to investigate the status of DBR in CCI. Of specific interest to us as researchers is if DBR can contribute to how

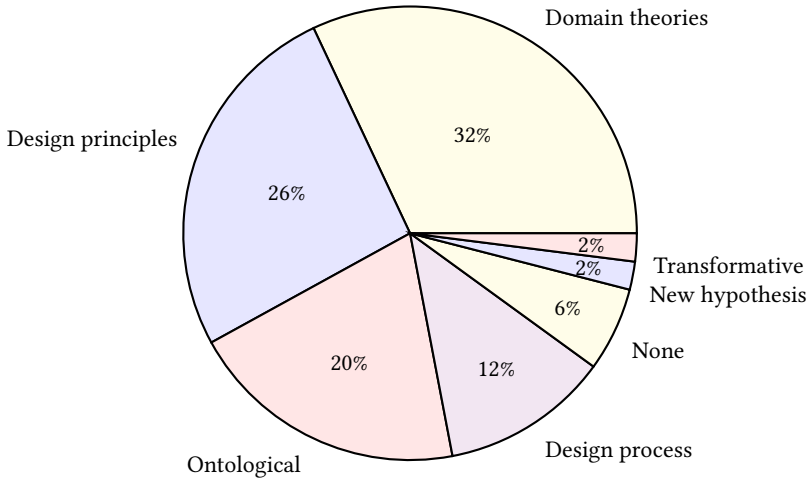

Figure 2: Type of knowledge contributions in CCI research using DBR based on a corpus of 50 papers. The categories are defined by Hoadley and Campos: Domain Theories, Design Principles or Patterns, Design Processes, Ontological Innovations, New Hypotheses, and Design Researcher Transformative Learning [95]. The results are limited to that we coded each paper for only one contribution type.

we perform research and what we can learn from it. Related to this Hoadley and Campos talk about four stages in a DBR process [95] and a recurring theme in texts about DBR is that there is a strong focus on the importance of knowledge development beyond the specific artefact the research is centered around. Before we discuss the results we illustrate with one example of good DBR practices in CCI by Malinverni et al. [124].

The objective of the study reported on by Malinverni et al. is to understand and compare the affordances of the Window-on-the-World (WoW) and the World-as-Support (WaS) paradigms to inform both theoretical and design research, and specifically investigate how these paradigms can shape the usage and meaning-making of the physical/digital environment and how they can influence social relationships [124]. When we look at the study through the characteristics pointed out by [13, 95] we can make a number of observations. The study is *grounded* in literature on traditional methods for supporting children in authoring stories, related work on mobile technologies and embodied interaction. The study is situated in a school as real *educational context* and is focused on the design and testing of a significant *intervention*, "Espaistory", which is an application aimed at supporting the collaborative authoring of site-specific narratives by children. *Mixed methods* are used, the researchers apply video recordings and multi-modal analysis [150]. In the *conjecturing* phase, the development process is *iterative*; first, they derived initial requirements from: 1) the review of related works; 2) the organization of workshops to support children's storytelling and 3) the collaboration with teachers at a local primary school, and subsequently, they developed a preliminary prototype for each paradigm for pilot testing. The researchers worked in a collaborative *partnership* between teachers as practitioners in a local school. In the *reflecting* phase, their experimental results suggest that the WaS paradigm promoted a higher level of engagement with space and afforded a larger number of instances for shared meaning construction and embodied interaction, compared to the WoW paradigm. The paper develops *re-usable design knowledge* in proposing the World-as-Support (WaS) interaction paradigm to address the rise of emerging approaches to design Augmented/Mixed Reality (ARMR) applications for mobile technologies, and thereby make an *ontological* contribution.

What we see in this example is how all the typical characteristics as pointed out by [13, 95] are present, and thereby serve as an example for how DBR can be adopted in CCI. The study utilizes multiple aspects of CCI research from its applied and theoretical nature both to inform and to learn from the design and use of an artifact in order to understand ways to create a desired change in the behaviors of the target group. Thus, the study offers an exemplar for incorporating conceptual and empirical research efforts oriented toward understanding how to develop technologies by taking into account an integrated examination of the manifold factors and potentials involved.

5.1 Research Contributions

The typical knowledge contribution from DBR is not a grand theory but rather some form of Intermediate-level knowledge [101]. However, this does not mean that it is less important to clearly report on what the contribution of the presented research is. Many of the forms of Intermediate-Level Knowledge presented by [29, 101] could be categorized under the categories suggested by Hoadley and Campos [95]. Looking further into the relationship between Intermediate-level knowledge and the categories suggested by Hoadley and Campos could be interesting future work. However, the first matter to work on is not exactly how we should categorize or denote the knowledge produced within DBR (and CCI in general) but that it becomes an important standard practice to report not only about an intervention, but also focus on what the intervention's knowledge contribution is.

Bringing in more DBR into CCI could lead to both enhanced research processes by applying procedures suggested by DBR, such as grounding, conjecturing, iterating, and reflecting [95] as well as better described knowledge contributions. Regarding the later, the various categories suggested by Hoadley and Campos [95] can serve as one source of inspiration but we acknowledge that there are other forms of knowledge contributions as well (see e.g. [192]).

Among the six forms of contributions typically appearing in DBR research [95], we found that there are no examples of *New hypothesis* at CHI and IJCCI, but only one at IDC [115], and that *Researchers transformative learning* is missing at IDC and IJCCI while there is only one example at CHI [166]. Scheepmaker et al. is an example of reflections after the project is over, which offer a more holistic approach to the whole design process rather than specific iterations [166]. One could argue for that Abrahamson could be in this category as well, however, they are quite explicit with the emerging taxonomy in the paper [3], why we chose to classify it as *ontological innovation* instead. This is similar to the only example of *New Hypothesis*, where Lee et al. explicitly argue for that the contribution consists of four new hypotheses [115]. Our coding is therefore primarily based on the authors own defined contribution, when possibly, rather than our own interpretation of the reported results. Also, in the analysis of the corpus, we coded each paper for only one contribution type, while in retrospect it would be more true to include more, as some research articles make more than one type of contribution [192].

5.2 Ways of Doing Research

Given that iteration in which a series of designs are developed and tested to learn from the previous phases and inform the next one, is commonly described as one of the key characteristics of DBR (e.g., [13, 95]), it was surprising to see that some papers in the corpus have not involved multiple iterations. More surprisingly, none of the conference papers with a *design process* type of knowledge contribution reported on the iterative aspect of their study, but rather reported on a particular phase without making any reflections on the accumulated knowledge across different phases of their DBR process. In the IJCCI papers we found two design process papers that mentioned iterations [17, 112]. Further studies that aim to make contribution to the knowledge of *design process* may focus on involving multiple phases to share experience and build an understanding of the iterative nature of DBR. Our observations are in line with Zheng [201], who reported that studies with a design-based research approach often fail to describe how the interventions have been revised. This contrasts with the idea within DBR that it is through an iterative process and stepwise refinements that knowledge is produced in DBR. To overcome the problem, and make the iterations more transparent, Tinoca et al. recommend listing each cycle/iteration and its full documentation (time, commitment, contingencies, activities, data collection, and analysis) [175]. Although this would be preferable, this might also not fit within the page limits that are typical for publication of papers at conferences like CHI or IDC. However, we see two examples of elaborated descriptions of iterations in IJCCI [22, 48]. Celepkolu et al. are explicit on the use of an iterative design-based research approach as defined by [57, 131]. They implemented two cycles of design, implementation, analysis, and evaluation phases, and they present each stage of the cycles in the method section of their paper [48]. The first iteration aimed to understand children's perceptions of two different types of visualizations (summative and time-series), and in the second iteration, it is clear how they redesigned some of these visualizations, added new features based on children's feedback, and conducted another user study. The outcomes of this iterative design-based research process led to implications for theory, design principles for better user experience and an application [48]. Bar-El and Worsley developed an inclusive making course and based their DBR approach on [26]. In the paper, they created conjecture maps [161] as a tool to capture their iterative design process, the connection between the course's theoretical underpinning, design elements, and their intended outcomes [22]. Two conjecture maps are presented to clearly explain changes made between the course iterations , which frame their results in terms of the intervention outcomes [22]. These two different examples of presenting iterations serve each of their purpose and can be inspiring for others who present results from DBR studies.

Another reason for the high number of papers not reporting on any iteration (30%) is that many of these do not focus a specific design, but are more processual or analytical in nature, for instance design session [159, 198], learning activities [44, 127, 165], or a retrospective analysis over 20 years of practice [3].

The setting where the data collection took place was rarely elaborated on, and sometimes hard to code. For instance, the relevance of the church context in [198] is difficult to judge. It is hard to say if the work described is situated in a real educational context, since it is not further elaborated in the paper beyond just simply stating that the church hosted the project [198]. This could be an educational context based on the mindset of families, and due to that the participants were recruited through an after-school setting, however the role of the context is not specifically elaborated on in the paper. We ended up with that all papers were situated in a real educational context in a sense that it is in a real-world setting and not in a lab, however, due to the lack of information, we have not coded for if this is the intended context for the intervention or only used just for data collection.

A difficult category is co-design based papers, such as e.g. in Yip et al. from CHI where it is unclear what the intervention is - if it is the families iteratively developed designs of mobile technology tools to promote science learning between parents and children or if it is the researcher's co-design methods [198]. Similarly, in Ribeiro et al. it is not clear if the interventions are the children's result from co-design, or if the researchers make any iterations [154]. These type of examples show the difficulty of coding for intervention and iteration, and an opportunity to describe more clearly for future DBR research in CCI.

Another type of paper that was difficult to code was Abrahamson, who practice DBR, but make retrospective analysis of his own pedagogical design projects over the past twenty years [3]. The result is a taxonomy of design genres for fostering mathematical insight, where he articulates and compares what he discerns therein as two distinct activity genres for grounding mathematical concepts. The work is clearly grounded in various DBR based projects, however, the methodological details and DBR practices of each study is not reported on here and was therefore difficult to code.

5.3 Recommendations

Based on the scoping review of DBR practices in CCI research, we will here make a number of recommendations for possible ways forward.

- 36 out of 93 papers (39%) identified in our initial search simply mention that they are doing 'design-based research' without referencing any DBR related source. This makes it difficult to know what the authors actually mean by saying that they are doing DBR. Including some reference to the concept makes it much easier for the readers to know what the authors are referring to.
- In the analysis of secondary resources (references used in the corpus), the review presents an overview of 49 inspiring references for DBR from the learning sciences that can be useful when designing a CCI research study and approach. The papers most frequently used in the reviewed CCI literature ([13, 26, 45, 55, 57, 60, 62, 163, 187]) together with the sources mentioned in section 2 could be a useful starting point while the rest [8, 12, 20, 21, 25, 33, 34, 39, 58, 59, 63, 68, 70–73, 75, 96, 103, 106, 111, 114, 129–131, 133, 141, 144, 147, 148, 152, 153, 160–162, 184, 190, 196, 199] can provide further input. For an overview of the most cited DBR references in CCI, see Table 2.
- The typical knowledge contribution from DBR is some form of intermediate-level knowledge [101]. However, although the knowledge contribution is e.g. some domain theory rather than a grand theory, it is important to be explicit about type of contribution, and how others can learn from it. The use of DBR can be a possibility to bridge the gap between educational practice and theory, since its goals are to both advance domain-specific theories about learning and design and develop the tools used to support the learning process [20].
- DBR has a high-level process consisting of four phases, grounding, conjecturing, iterating, and reflecting [95]. Although this is quite similar to the typical practice in CCI design research, it can still serve as inspiration for the CCI community, in order to further knowledge and theory and that the interventions created within DBR need to go beyond being product development for better learning environments, see e.g. [26, 55].
- In terms of context, it helps the understanding of the results if it is clarified how the study is situated in a real educational context. This can either be through the physical context (e.g. classroom) or based on the participants expectations of participating in educational activities even if the physical context might not be obvious for the reader (e.g. in church [198], or a private room in a school [100]).
- In order to better understand the result of the research, we recommend to clearly describe the various iterations leading up to the maturing intervention and the theoretical understanding. As mentioned above, this is in line with observations in reviews of DBR literature like the systemetic review by Zheng [201].

5.4 Limitations

Before finalizing, we outline the identified limitations of this review. A scoping review aims to provide a current, focused snapshot of a research area or field [16]. As such, this review showcases a limited number of papers that do not represent DBR in CCI as a whole. It is likely that we missed some relevant papers due to our search strategy, chosen databases or time frame of conducting searches. We acknowledge that the single search term 'design-based research' does not justify all relevant work that is published in this area. Other terms are sometimes used, such as e.g. design experiments, or developmental research. We further acknowledge that the venues IDC, CHI and IJCCI and the databases ACM Digital Library and Scopus are not the only venues relevant for design-based research practices in CCI. Due to these limitations, we make no claims to cover the whole field of design-based research practices in CCI, but rather provide a situated snapshot of the current landscape of research in CCI.

6 CONCLUSION

In this paper we have presented a scoping review regarding the use of Design-Based Research (DBR) to perform and report on research in CCI. We believe that ideas from DBR could be useful in order to organize and describe research with a strong design component, particularly related to learning interventions. Further, the strong focus on knowledge development in the literature describing and arguing for the use of DBR is something that the CCI field could benefit from and be inspired by. It is our hope that this paper can inspire CCI researchers to apply DBR, and that it can contribute to the continued growth of knowledge development and maturation of the field.

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7 SELECTION AND PARTICIPATION OF CHILDREN

No children participated in this work.

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