A Brief Systematic Mapping of Literature on Designing STEM Curricula Using Design-Based Research

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Abstract: This brief systematic mapping study examines existing research on designing STEM curricula through Design-Based Research (DBR) in formal and informal learning environments. Through analysis of peer-reviewed literature from major educational databases, we identified patterns in existing literature to highlight applications of DBR cycles in STEM curriculum development and common design principles and expose gaps in current literature. This mapping study gives researchers and practitioners an overview of DBR's role in STEM curriculum design.

Introduction

Design-based research (DBR) is a valuable methodology for guiding, iteratively developing, and refining Science, Technology, Engineering, and Mathematics (STEM) curricula. This systematic literature mapping aims to identify the findings from studies that have used DBR to design and evaluate STEM curricula in formal and informal settings. We employed the PICO framework (Stone, 2002) to structure our research question and the PRISMA methodology (Page et al., 2021) to ensure a comprehensive and transparent review process. We will also discuss the challenges and limitations encountered in the iterative design process of STEM curricula within DBR studies.

Theoretical Framework and Necessity of Design-Based Research

The theoretical framework of constructivism guides the iterative design process in developing STEM curricula. Constructivism emphasizes that learners actively construct knowledge through their experiences and interactions with their environment (Piaget, 1954; Vygotsky, 1978). In our study, constructivist principles inform the iterative design process of DBR, where learners actively engage in designing and constructing their understanding of scientific and mathematical concepts (Papavlasopoulou et al., 2019). Design-based research is a methodological approach that involves iterative development to create practical solutions in real context to intricate educational challenges and contributes to the theoretical understanding of the work (McKenney & Reeves, 2019). DBR primarily emerges from frustration stemming from the insufficient impact of educational research on the educational system, and it aims to bridge the gap between theory and practice. Traditional controlled experiments fail to capture the complex nature of a classroom environment and have less impact on improving educational practices (Reeves, 2000). Therefore, it is important to situate research within authentic contexts and to foster collaboration between researchers and practitioners (Cobb et al., 2003; The Design-Based Research Collective, 2003).

Methods

Systematic mapping of literature was carried out to get an overview of the studies that used the iterative process of DBR to design STEM curricula in formal and informal settings. Systematic mapping examines the extent and nature of research studies, outlines the research trends, and helps researchers identify gaps in the existing literature (Arksey & O'Malley, 2005; Kitchenham et al., 2011). For our purpose, this methodology is appropriate to answer the research question: What research exists on designing STEM curricula through the iterative process of DBR in informal and formal settings?

Search

For this systematic mapping study, the PICO (Population, Intervention, Comparison, Outcome Measures) framework (see Table 1) is used. PICO framework is a structured approach commonly used in systematic mapping studies to guide the literature search and selection process (Stone, 2002). We used the combinations of relevant keywords and Boolean operators AND, OR, using (Design-Based Research OR Iterative Process) for the title, AND (STEM curriculum OR STEM curricula) for all text. We used our university's library system to search for academic articles. The system retrieved articles from several databases such as SCOPUS, Academic Search Premier, ERIC, Complementary Index, and Directory of Open Access Journals.

Table 1

PICO chart illustrating accurate keywords and search terms

Quantitative studies	Qualitative studies	Terms
P – Population	P – Population	STEM educators and Learners

I – Intervention	I – phenomenon of Interest	STEM curricula OR STEM curriculum
C – Comparison	Co – Context	Design-based research OR Iterative process
O – Outcome measures		Any

Study Selection

The following inclusion and exclusion criteria were applied to titles and abstracts.

Inclusion criteria:

- Studies are in the field of STEM curricula design and development, and DBR is applied to the iterative process.
- Studies were published before January 1, 2024.

Exclusion criteria:

- Studies mention DBR but do not actually apply it in the iterative process of designing STEM curricula.
- Studies that are not peer-reviewed
- Studies that are not in English
- Studies that are not accessible in full-text
- Books and gray literature
- Duplicate studies

Figure 1

PRISMA flow chart for identification of studies via databases and registers.

We followed the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guideline to identify and report the studies (Page et al., 2021) (see Figure 1). After reviewing the titles, abstracts, and keywords, 82 articles were identified for a screening process adhering to the inclusion and exclusion criteria. 17 duplicates were removed from the records. 35 articles were excluded by title and abstract. The exclusions were based on the articles using the term DBR in the abstract and/or keywords, but were not actually used in the full text of the paper in a meaningful manner. We could not retrieve the full text for five articles. We retrieved 25 articles for a full-text review.

Data Extraction

Full-text data from the remaining 25 potentially relevant articles were extracted for reading and final inclusion. 13 articles were excluded because they did not include the iterative process of designing STEM curricula or they did not provide substantial information regarding the research question. For example, some studies focused on the impact of design-based STEM curricula on student performance and achievement (Selcen Guzey et al., 2016; Fan & Yu, 2017) or the development of tools for the classroom through the DBR process (Jung & Mercier, 2023). Twelve articles met all the inclusion criteria and were meaningful for the purpose of our study. The findings from those articles will be reported in the findings section.

Findings

To answer the research question, we thoroughly read the final articles and color-coded them under themes in a spreadsheet. Findings from the literature are summarized below:

- Participatory and collaborative curriculum design: When teachers and stakeholders are involved in the participatory design process as "co-participants," they feel more empowered and more likely to sustain the implementation (Barab & Squire, 2004, p. 3; John et al., 2018). McFadden & Roehrig (2017) emphasize the importance of active classroom teachers in the design team to create a STEM-integrated curriculum. Wu et al. (2021) articulated design principles to guide STEM pre-service teacher training.
- Engineering design process: The reviewed literature emphasizes the integration of engineering design in developing a STEM curriculum (John et al., 2018; Parker et al., 2016). Jung and Mercier (2023) elaborated on designing collaborative tools for engineering education classrooms, emphasizing trade-offs in the DBR process.
- DBR across K-12 grade levels: DBR research was used to design and develop a STEM curriculum employing an iterative participatory approach at the early childhood level (John et al., 2018). Kim et al. (2015) designed an iteratively developed curriculum for technology-enabled science classrooms at the elementary level. Li et al. (2022) used DBR to design an arts-forward STEM curriculum. Researchers have also iteratively designed the curriculum at the middle school (Terrazas-Arellanes et al., 2017) and the high school level (Pugh et al., 2023).
- Application to informal spaces: DBR is used to develop a transformative experience intervention (Pugh et al., 2023) and STEM learning in public spaces (Cardiel et al., 2016), demonstrating the impact of iterative design cycles on improving student engagement and learning outcomes. Papavlasopoulou et al. (2019) used DBR to optimize students' informal learning experiences in a constructionism-based coding project.
- Professional Development: This theme is crucial as it demonstrates how teachers can be more empowered to use DBR in designing the curriculum and its role in teacher preparation programs. McFadden and Roehrig (2017) highlight the importance of teamwork and collaborative efforts in designing STEM-integrated curricula. Wu et al. (2021) emphasize having pre-service teachers gain design expertise through virtual internships.

We found gaps in the reviewed literature, such as limited research on reporting detailed iterative processes to design STEM curricula, customizing DBR curricula for diverse student populations, and the long-term sustainability and scaling of DBR-developed STEM curricula.

Discussions

This brief systematic mapping study provides an overview of using DBR in designing STEM curricula and what needs to be added. Although the scope of our study was limited, this study highlights the importance of using DBR processes in developing and refining STEM curricula. The findings highlight the value of the iterative curriculum development process while identifying literature gaps. Future research can customize DBR for diverse student populations by integrating immersive technologies that allow students to engage in place-based STEM learning in ways that are authentic to their cultural heritage (Stansberry et al., 2023). Future studies can also explore how DBR supports teachers in co-designing culturally relevant virtual tours using open-source VR platforms, integrating Indigenous knowledge with STEM concepts (Panwar et al., 2024). We recommend involving community elders and cultural experts and using a "relationship-first" approach (Gardner-Vandy et al., 2024) when working with Indigenous communities in co-designing the curriculum. We also recommend leveraging digital technologies to document storytelling-based STEM learning that connects scientific concepts to students' lived experiences through visuals or snapshots of the curriculum development process accompanying interview transcripts of the curriculum development team (Panwar & Vasinda, 2023). Researchers can take cues from the practices identified in this study, which can help guide future curriculum development efforts. However, a broader literature review is recommended to study the detailed iterative process of DBR designing STEM curricula for a diverse student population.

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