USING DESIGN-BASED RESEARCH TO EXPLORE HIGH SCHOOL STUDENTS' INFORMAL LEARNING OF MATHEMATICS

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As the demand for STEM jobs increases, central to the success of STEM education and careers is a strong foundation in mathematics. However, students' interest in mathematics is often very low. Thus, it is imperative to cultivate interest in mathematics among high school students. To promote students' interests and positive attitudes in mathematics, we implemented informal learning using design-based research (DBR). We show that DBR is a compelling and suitable methodology for our research aims. Then we report how DBR can extend from previous studies in using informal learning for mathematics and foster motivating learning ecology in a school setting. Our DBR project has completed four iterations.

Keywords: Informal Education; Design Experiments; Affect, Emotion, Beliefs, and Attitudes; High School Education

It is well known that global job growth will be mostly concentrated in the high-skilled areas of healthcare and STEM (McKinsey & Company, 2023). For example, the US Bureau of Labor Statistics (2023) projected a 15% overall growth of computer and mathematical jobs in the next eight years, with jobs in data science and statistics experiencing 35.8% and 32.7% increases, respectively. However, education statistics imply that the supply of mathematicians and scientists entering those fields may soon be insufficient to satisfy the demand. The awarded mathematics and statistics bachelor's degrees growth rate is significantly lower than other STEM fields, despite an increasing trend of the overall STEM fields. According to Digest of Education Statistics (2023, Table 322.10), over the past decade, the annual growth rate of awarded bachelor's degrees in computer and information sciences was 22 times higher than that of mathematics and statistics, engineering growth 12 times higher, and biological and biomedical sciences growth 9 times higher. The number of high school students completing advanced mathematics courses (i.e., calculus) declined in the decade of 2009-2019 (NCES, 2022). Thus, it is imperative to cultivate interest in mathematics among high school students, which will eventually align the number of college students pursuing STEM degrees with workforce needs.

Informal learning, a type of *less classroom-bound, free-choice education* (Falk, 2001), has recently gained traction for improving STEM learning and for improving engagement in mathematics (Denson et al., 2015; Pattison, Rubin, & Write, 2017; Waldock et al., 2016). The "informal" and "free-choice" characteristics of informal learning make it an ideal medium for delivering education in uncertain times, offering a "free-choice" approach to engaging with information and knowledge. Cultivating positive mathematics or STEM identities is often a central focus for designers of informal learning experiences (Bell & Bevan, 2015; Feder et al., 2009; Zimmerman & Bell, 2012). We suggest that design-based research (DBR) from the learning sciences is a compelling and suitable methodology for exploration of both informal learning of mathematics and its outcomes measurement among high school students. In this paper, we report how DBR can extend previous studies in using informal learning for mathematics and foster motivating learning ecology in school settings. To exemplify, we briefly report on an NSF-sponsored DBR project that completed four iterations.

Theoretical Framework and Research Aims

Drawing on theories of experiential learning (Kolb, 1984) and related to active learning programs that have been shown to increase performance and motivation in STEM (Freeman et al., 2014; Weinberg et al., 2011), informal learning, as a type of less classroom-bound and more free-choice education (Falk, 2001), includes a wide array of experiential learning instances that happen when students actively engage in learning opportunities outside of the traditional context of teacher and classroom. Much of the research on informal learning emphasizes identity, seeking to influence identity as well as to understand identity development (Bell et al., 2009; Pattison et al., 2017). Math identity is believed to be an important component of students' achieving success in mathematics (Allen & Schnell, 2016; Bohrnstedt et al., 2020; Gonzalez et al., 2020). Identity work can be conceptualized as a process of alignment, drawing upon Anderson's (2007) four-dimensional model of mathematical identity as well as Wenger's (1998) three modes of being – alignment, imagination, and engagement. Furthermore, studies have shown that peer and near-peer led activities have a strongly positive impact on students (Brownell & Swaner, 2010; Carrell & Sacerdote, 2013; Cracolice & Deming, 2001; Quitadamo et al., 2009; Trujillo et al, 2015; Williams, 2009). In our project, we combined the processes of mathematical identity alignment with the supporting structure of near-peer mentoring.

Differing from many existing educational studies on informal learning that focused on activities held mainly in certain out-of-school or after-school settings, we seek a design scheme or solution for the infusion of near-peer, informal learning of mathematics for high school students in the school setting.

DBR – Literature Review and Why

Brown (1992) defined DBR in her seminal paper, followed by many literature references to DBR, including earlier ones focusing on the "what" and more recent papers shifting to the "how" of DBR (Puntambekar, 2018). Extending Anderson and Shattuck's (2012) review of the potential of DBR, of the characteristics of good DBR studies, and of the growing popularity of DBR approaches in educational research, Fowler et al. (2022) reviewed DBR studies completed in the decade up to 2011. Beyond being a specific research method, DBR is an approach that centers a series of iterative (often educational) designs as the unit of investigation, and frequently employs mixed research methods and tools. Two recent studies (Hoadley & Campos, 2022; Scott et al., 2020) demonstrated DBR's implementations in online learning and biology education. Scott et al. (2020) summarized what DBR is and pointed out four differences between DBR and experimental approaches, which deserves readers' special attention because most researchers and scientists are well trained for experimental approaches rather than DBR method.

Why We Chose DBR?

Design-based research (DBR) from the learning sciences, although considered a relatively young (about three decades old) educational research methodology, is compelling and suitable for our research aims. DBR has no solid requirements of instructional intervention form or evaluation measurements. Rather, the intervention design as well as outcome measurements can be developed or employed during the design process (Anderson & Shattuck, 2012; Sandoval, 2014). DBR focuses on investigating what the design process is and how it can be generalized (Cobb et al., 2003). Due to these features of DBR, it is suitable for innovative research in certain learning scenarios, such as ours. Tailoring the intervention and implementation process needs multiple iterations instead of a one-shot deal. Furthermore, the DBR approach enables a flexible methodology that accommodates specific situations, proving resilient and robust even in highly uncertain times. Notably, our project commenced amidst the COVID pandemic, and the DBR approach facilitated the customization of each iteration to suit the unique circumstances of each time period, as well as the progressing of our research agenda.

Our DBR Project

Following preliminary explorations and a smaller scale pilot study (Wilson and Grigorian, 2018) showing that near peer interventions have the potential to positively affect attitudes to mathematics, we carried out an NSF-funded project on informal learning of mathematics. Over the course of three years, this project involved 1,258 students from four high schools in two majority-Hispanic school districts in South Texas.

DBR Iterative Redesign Process

The DBR iterative redesign process is visually represented in Figure 1. In each iteration, the evaluation of both the delivery of the experiences and the data collection processes provided insights that informed the subsequent iteration's design. This resulted in a continuous cycle of innovation, evaluation, and refinement that ensured the experiences and the associated research methodologies remained responsive and adaptable to the unique learning contexts and challenges encountered throughout the project duration. To illustrate our design process for informal learning of mathematics in a school setting, we summarize the iterations.

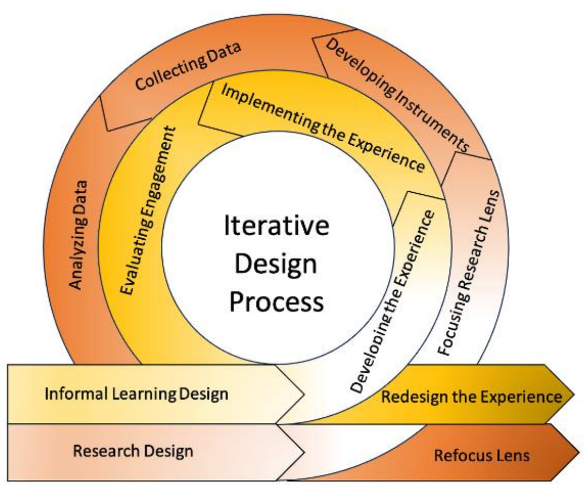

Figure 1: Iterative Informal Learning and Research Design Processes

The 1st iteration. We started in spring 2021 with fully online, synchronous MathShows presented to groups of classes via Google classrooms. The online modality was precipitated by COVID-19 pandemic restrictions. Viewing of brief pre-recorded video scenes produced by college student near-peers followed by live interactions with same near-peers via video and chat.

The 2nd iteration. An easing of COVID restrictions and resumption of in-person schooling required changes in the program design in Fall 2021. For this iteration, live, in-person MathShows were performed in a large school auditorium, with multiple classrooms in attendance simultaneously and combined viewing of pre-recorded video scenes and interactive activities with near-peer mentors.

The 3rd iteration. Live, in-person MathShows were performed in a large school auditorium, with multiple classrooms in attendance simultaneously. There were no pre-recorded video scenes, with more audience interaction, more prize opportunities for students, and more scripted acting by near-peers.

The 4th iteration. Live, in-person MathShows were performed by a smaller cast of near-peer mentors in individual classrooms, not in an auditorium. This allowed much more direct interaction between students and near-peer mentors, but each MathShow was shorter.

DBR-Iterative Instrument Design

DBR experiments are resource intensive (Scott et al. 2020). For the research aims of our DBR project, we collected large amount of qualitative and quantitative data via mixed methods. We hereby spotlight one instrument item for its iterative design process. During the 1st and 2nd iterations, as one of the main quantitative measures, this study used a mathematics identity survey item that was adapted from well-established attitude surveys. Students were asked to choose from a Venn diagram to describe how much they align with being a mathematician. In the focus group studies during the 1st and 2nd iterations, high school students shared their various perceptions of a mathematician. We followed up by asking them the reason for their response to the math alignment question. These qualitative studies revealed to us that when respondents saw the Venn diagram, the circle of "Mathematician" may have different meanings to them and also students have different reasons for making their choice. To capture these differences in perception, based on students' focus group input and using some of their exact words, we developed two novel items for surveys for subsequent DBR iterations to collect students' understanding of mathematician and reasons for their alignment choices.

Discussion and Conclusion

Our project shows that by employing DBR for designing and studying learning interventions, mathematics educators can develop both theory and practices for the informal learning of mathematics. For instance, the identity-measurement instruments developed in our DBR process exemplify how DBR invites utilization of mixed methods synergically. An example in this study of qualitative research informing quantitative research is that focus group interviews (qualitative research) captured students' perceptions of who a mathematician is. We then developed two more survey items (quantitative research) with choices written based on those high school students' words. On the other hand, as an example of quantitative research informing qualitative research, in later iterations, focus group studies consisted of participants pseudo-randomly recruited with a stratified sampling method based on certain quantitative data to ensure the inclusiveness of different types of students in the focus group. In addition, the design scheme developed in our DBR project is generalizable to broader learning settings. Middle and elementary schools are potential places for informal learning of mathematics. Moreover, math teachers may also be able to incorporate short and attention-catching informal learning components in their classrooms that nurture students' positive academic emotions. Similar expansion can be made to colleges as well.

Acknowledgments

We are grateful to the many teachers and students who participated in this research study. We are grateful for the generous support of this study provided by the NSF AISL grant #2006067. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

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