improve student attitudes toward and interest in STEM disciplines [3]–[5]. However, studies of classroom implementation of digital fabrication technologies also report that teachers struggle to move beyond "keychain syndrome," the tendency to fall back to reproducing simple objects, such as a keychain or coaster, that entail little to no student-driven problem-solving or engagement in authentic design thinking [6], [7].

Design thinking encompasses a set of principles that, when coupled with *making*, may provide a more authentic and meaningful experience for students and help teachers move beyond the "keychain syndrome". Design thinking is a non-linear cognitive strategy used to approach the design of systems and solutions through collaborative and user-focused practices [8]. In the classroom, preliminary research suggests that design thinking is an effective model for teaching "21st century skills" that are also crucial to the development of science and engineering practices (e.g., collaboration, creativity, communication) [9]–[12]. As an engineering design process, design thinking organizes product creation around an empathetic understanding of the end-user's needs [8], [13]. An understanding of the user is intentionally

developed through a variety of data sources, including surveys, interviews, and observations. Rather than moving prescriptively through a rigid series of steps, design thinking allows a designer to move fluidly between stages in response to changes in the users' needs or the extent to which those needs are understood [14].

Teacher PL focused on *making* has generally centered on machine operation, and not pedagogy, cognitive strategies, and processes to situate the technology [15]. This project, Makers by Design (MBD), represents an effort to build teachers' understanding of design thinking so *making* can be situated within meaningful design activities for students that foster interest and skills development. From a STEM workforce development perspective, it is essential students develop proficiency in design-related skills for future success in STEM careers, including technical positions that require problem-solving, communication, collaboration, and other aspects of design thinking.

This paper presents results from an NSF-funded Advanced Technological Education (ATE) project that aimed to help in-service educators integrate design thinking into their practice. Seventeen educators from the Northern Virginia region were recruited to a 9-month fellowship consisting of a) 20 hours of professional learning in design thinking at Northern Virginia Community College's (NVCC) makerspace, b) practice teaching design thinking at a digital fabrication summer camp with middle and high school students, and c) lesson planning to facilitate design thinking into their instructional setting. This cohort of educators had representatives from K-12, public libraries, post-secondary institutions, and a wide range of disciplinary backgrounds. Data collection and analysis were designed to answer two questions:

1. To what extent does participation in the professional learning fellowship foster the integration of design thinking elements into instruction?

2. To what extent does the fellowship improve participants' confidence in implementing design thinking and digital fabrication?

Methods

Effective Professional Learning. Research on PL suggests that interventions that foster sustainable changes in teaching practice include (a) modeling, (b) lesson plan development, (c) practice teaching, (d) coaching, and (e) building a community of practice. Modeling desirable instructional practices provides teachers with the opportunity to experience exemplary, authentic instruction as learners [16]. *Modeling* has shown utility in several areas of STEM education, including engineering instruction [17], digital technology use [18], [19], and reform-based science instruction [20]. *Lesson planning* allows teachers to revisit and apply what they learn in an active way that is relevant to their own instructional context (e.g., grade, student ability, content) [16], [21]. Teachers value opportunities to *practice* using new instructional strategies in conditions without repercussions if a lesson does not go as planned [22]. Individualized *coaching* allows PL implementers to differentiate support based on teachers' needs [23].

Program Recruitment. Educators were recruited for the PL fellowship through contacts with local school districts and library systems and internally at NOVA. The application process required demographic data and brief narratives of prior experiences with design thinking, engineering, and