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Youth's Engagement as Scientists and Engineers in an Afterschool Making and Tinkering Program

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Abstract Making and tinkering is currently gaining traction as an interdisciplinary approach to education. However, little is known about how these activities and explorations in formal and informal learning spaces address the content and skills common to professionals across science, technology, engineering, and mathematics. As such, the purpose of this qualitative study was to examine how youth were engaged in the eight science and engineering practices outlined within the US Next Generation Science Standards within an informal learning environment utilizing principles of tinkering within the daily activities. Findings highlight how youth and facilitators engaged and enacted in practices common to scientists and engineers. Yet, in this study, enactment of these practices "looked" differently than might be expected in a formal learning environment such as a laboratory setting. For example, in this setting, students were observed carrying out trials on their design as opposed to carrying out a formal scientific investigation. Results also highlight instances of doing science and engineering not explicitly stated within parameters of formal education documents in the USA, such as experiences with failure.

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Introduction

Despite scholarly evidence that associate play with increased levels of attention, learning, and ways to explore and enact science identities (Andrée and Lager-Nyqvist 2013; Hirsh-Paek et al. 2009), the amount of time spent in leisure activities (e.g., being outdoors, reading non-school related material) by youth in schools and home environments has been diminishing for many years (Hofferth 2009; Hofferth and Sandburg 2001; Zigler et al. 2004). *Making* is a recent phenomenon considered by some to be a form of *experimental* play (Dougherty 2013) or a means for youth to attach new meanings to everyday objects through pretend play (Wohlwend et al. 2017). While others define it as a “class of activities focused on designing, building, modifying, and/or repurposing material objects, for *play* or useful ends, oriented toward making a ‘product’ of some sort that can be used, interacted with, or demonstrated,” (Vossoughi and Bevan 2014, p. 3; italics added for emphasis).

Making is currently gaining traction as an interdisciplinary approach to education and a possible means to increase the number of students pursuing science, technology, engineering, and/or mathematics (STEM) degrees and careers (Honey and Kanter 2013; Vossoughi and Bevan 2014). While many believe there is promise in making (e.g., Martin 2015; Martin and Dixon 2017), we know little about how these activities implemented within formal (e.g., classroom) and informal (e.g., after-school programs) learning spaces address various skills common to professionals within STEM fields. With the increase of making programs specifically designed for youth (i.e., youth-based makerspaces) in both formal and informal settings (Peppler et al. 2015a), a lack of knowledge of the skills developed through making activities is an important problem to address because policymakers, formal and informal educators, administrators, and community leaders do not have the information they need to make informed decisions about the implementation of making to address the learning and teaching of STEM.

It is important to note here that some have found it necessary to delineate between making and tinkering. The Oxford English Dictionary (2017) defined tinkering as “To work at something (immaterial) clumsily or imperfectly, esp. in the way of attempted repair or improvement.” Some definitions of tinkering include activities “characterized by improvisational, creative problem-solving” (Vossoughi and Bevan 2014, p. 9) through exploration of new technological material and techniques, as well as experimenting with various objects, tasks, and ideas (Martinez and Stager 2013; Peppler et al. 2017). Others have described it as “characterized by a playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new” (Resnick and Rosenbaum 2013, p. 164). And yet others connect tinkering with play, and describe as follows: “Playing (also called tinkering, messing about, messing around) is often generative, allows for risk-taking, is autonomous, often involves the hands, is pleasurable, is open-ended, and intrinsically motivated” (Jones et al. 2000, p. 761).

We generally view making as the process of creating something from separate pieces that, when combined, yield something more useful toward the goal than the individual pieces. Tinkering, we feel, is the process of taking something that already exists, and adjusting for improvement through playful experimentation. While there are slight variations in meaning here, we see this separation as mostly an issue of semantics and not central to this study: thus, in this paper we will use the two interchangeably. In this study, youth were provided opportunities for creating their own objects made of smaller components as well as tinkering with various tools and materials within a 6-week program focused on electricity and circuitry. This opportunity affords youth to develop skills and practices as novice makers (Ito et al. 2009).

As such, the aim of this study is to establish a foundation to inform and support the expansion of making programs by examining how youth are engaged in science and engineering practices within an informal learning environment utilizing tinkering as a general pedagogy and approach to making and tinkering.

Literature Review

STEM education has increasingly gained importance on an international scale as a way to develop a globally competitive workforce in a technological world (Maltese and Harsh 2015; Denson et al. 2015). Furthermore, since the majority of learning takes place outside of school, informal and afterschool settings provide ideal opportunities for examining STEM teaching and learning (Denson et al. 2015; Rennie 2007) in environments typically different from school. Activities and tasks within afterschool programs are more open ended, encourage mutual negotiations and collaboration, contain more uncertainty and foster more commitment—a hands-on and minds-on setting (Sahin et al. 2014). Opportunities for learning STEM concepts outside of school are rapidly increasing and studies examining the benefits and outcomes of these programs are beginning to emerge. Research on students attending afterschool STEM programs have documented benefits for students including increasing interest in STEM, attitudes toward the fields of science and engineering, efficacy for *doing* STEM, and cognitive and social skills (e.g., Krishnamurthi et al. 2013; MacEwan 2013).

While an extensive body of scholarship is focused on research in informal education (Bell et al. 2009), most relevant to this study is the notion that active engagement in STEM activities via afterschool and extracurricular programs seems to lead to increasing efficacy for *doing* STEM (Denson et al. 2015; Krishnamurthi et al. 2013; Rappa and Tang 2016). In other words, we focus on activities and outcomes related to common science and engineering practices related to the *scientific method*. For example, Denson et al. (2015) concluded that engagement in their co-curricular program by high school minority students led to an increase in being able to apply mathematical and science concepts to real world situations and gaining a sense of accomplishment in attaining a set goal or winning a competition (Denson et al. 2015). Additionally, twenty-six 11 to 12-year-olds engaged in a robotics summer camp were found to engage in science process skills (e.g., observation, hypothesis generation) common to the field of science in solving a problem utilizing robotics (Sullivan 2008). Krishnamurthi et al. (2013) defined this outcome as “I can do STEM,” which include, but are not limited to demonstration of STEM skills (like formulating questions, testing, predicting observing) and demonstration of engaging in critical thinking and problem solving. Sahin et al. (2014) too found that their afterschool program, which offered open-ended and scientific investigations across STEM fields, resulted in promoting twenty-first century skills in students grades 4–12, particularly complex communication and collaboration skills necessary for success in STEM careers.

Maker education is a new label being placed on types of afterschool and informal programs being offered to youth. In particular, a subset of this sort of informal STEM-focused learning includes “making” programs that are gaining in popularity (Peppler et al. 2017). The maker movement consists of a culture of hands-on making, creating, and designing, and includes subjects like textile craft, robotics, cooking, electronics, and mechanical repair and creation (Dougherty 2013; Peppler and Bender 2013). The maker movement is perceived to be a driver of creativity, excitement, and innovation for inquiry-based learning and pursuing STEM careers (Bevan et al. 2015).

As for the qualities of makerspaces that facilitate learning, Quinn and Bell (2013) claimed that informal learning environments provide entry points for science learning and provide a more ecological and lifelong view of learning that is different from most classrooms. This idea was confirmed by Peppler and colleagues (2015b) in that makerspaces provide youth an opportunity to engage in practices common to engineers. Additionally, Petrich et al. (2013) described what learning looks like within the context of making, noting that learning is highly dependent on what the learners already know coming into the space and how they pursue their individual interests. Learning through making was also observed as engagement (active participation), intentionality (purposeful and evolving pursuit of an idea of plan), innovation (new strategies that emerge through growing understanding of tools/materials/phenomena), and solidarity (sharing and supporting others) (Bevan et al. 2015). Gross and Do (2009) define other qualities of maker programs that facilitate creative engagement such as owning the problem, using the design-play mentality, and using tools to make things.

Petrich et al. (2013) asserted that tinkering involves meaningful scientific and engineering practices via a process they call “thinking with your hands” (p. 53). While the learner may be silently working with their hands, the authors claimed it is clear that embedded within the things they build, children are learning about the theories and properties of materials. Likewise, children come to understand the engineering process and scientific phenomena through iterative design and testing. In addition, youth engaged in tinkering-related activities and programs participate in collaborative argumentation (Kim and Zimmerman 2017), develop computational skills specific to robotics (Bers et al. 2014), and build meaningful relationships with facilitators (DiGiacomo and Gutiérrez 2016). Resnick and Rosenbaum (2013) even argue that tinkering is a valuable strategy for understanding how to adapt and improvise old plans and ideas when new problems and situations arise. As such, making and tinkering represents an expanded view of traditional constructivist theories and includes conceptions of the socially situated developing self where learning is signaled by participation in social activities that expand the learners’ knowledge, skills and interests (Petrich et al. 2013).

To date, few studies with a focus on afterschool programs examine engagement with practices as researchers tend to examine academic, behavioral, emotional and social outcomes (e.g., Durlak et al. 2010; Roth et al. 2010). In addition, few studies have attempted to map informal maker education onto learning standards such as the Next Generation Science and Engineering Standards (NGSS; National Research Council [NRC] 2012). MacEwan (2013) discussed how informal afterschool settings may provide *disguised learning* where participants have fun while also learning skills that translate to multiple STEM outcomes, particularly through critical thinking and problem solving rather than focusing on vocabulary and rote memorization. Furthermore, Krishnamurthi and colleagues (Krishnamurthi et al. 2013) suggested that there might be a disparity between how stakeholders rate learning indicators versus the actual outcomes of a given program. For example, teamwork has been discussed as a main outcome of afterschool programs but this is largely missing from standards. Many informal educators assert that content standards may be of low importance for informal settings and that informal education should focus on building other sorts of skills (Falk et al. 2014). However, we contend that STEM content and practice standards may have great relevance to these types of settings and that informal programs may give youth an opportunity to actively participate in science and engineering practices. Thus, more research needs to be done to operationalize what STEM outcomes look like in the context of informal learning, particularly in relation to common practices engaged by scientists and engineers.

Lastly, and most relevant to our study, Petrich et al. (2013) reflected on what tinkering can offer to implementing engineering content and practice standards embedded in formal educational settings. The authors asserted that tinkering makes an important contribution to STEM education because it embeds engineering practices in purposeful and valued activities and provides students with skills that are authentic and have meaning and purpose, which is different from simply observing or taking notes in a classroom where students have minimal stake in the outcomes as it is just an exercise. Also, tinkering emphasizes the process of pursuing ideas, becoming frustrated and achieving breakthroughs in one’s own ingenuity and persistence—traits that are just as important to STEM as inquiry skills and science content (Petrich et al. 2013). However, all of these assertions are primarily anecdotal by the authors and a systematic examination of formal science and engineering practice standards with afterschool STEM learning has yet to be undertaken. Therefore, this study builds upon our current understanding of making and tinkering within an informal learning environment, and expands upon the current literature base regarding outcomes of afterschool, informal educational programs, by answering the following research question: *How are youth engaged in science and engineering practices in an informal after-school program based on principles of making and tinkering?*

Conceptual Perspective

In this paper, we propose that learning through tinkering frequently involves participating in the actions of scientists, technologists, engineers, and mathematicians, which is intertwined with becoming a member of the broader STEM community. Through participation in community-relevant activities and practices, youth, as newcomers or peripheral participants in the STEM community, are provided with opportunities to begin developing the knowledge and skills to move toward full participation and life-long learning in the STEM community (Lave 1991; Lave and Wenger 1991; Roth and Lee 2004). Learning “implies becoming a full participant, a member, a kind of person... Who you are becoming shapes crucially and fundamentally what you ‘know.’ ‘What you know’ may be better thought of as *doing* rather than having something” (Lave and Wenger 1991, p. 53, 157; italics added for emphasis).

Engagement and participation in activities and practices are more than completing a task that has no meaning or relevance to the student(s), but authentic in the sense that the task or problem is significant and common to those in the STEM community (Allie et al. 2009; Brahms and Crowley 2016; Lave and Wenger 1991; Sadler 2009). As an example, Jonassen et al. (2006) noted how engineers frequently encounter ill-structured and poorly defined problems that require collaboration with one another and with individuals outside the community of engineers. Therefore, engineering students should be expected to engage in similar problems as part of their curriculum (Allie et al. 2009; Sadler 2009). Within the context of tinkering, youth, as newcomers, are engaged in interest-driven problems and collaborative activities and practices not only common to makers, but common to members of the STEM community (e.g., Happy City Problem, see Bennett and Monahan 2013); authentic problems that encourage learning STEM content and skills, engineering design practices, use of tools, working as a team, and persistence through moments of failure to name a few (Bevan et al. 2015; Brahms and Crowley 2016; Quinn and Bell 2013; Thomas 2014).

At this point, we need to unpack our use and understanding of community—more specifically our use of community in the context of STEM. We view STEM as more than an acronym that refers to the four disciplines or occupations (e.g., National Science Foundation 2015), but as a community of practice defined as a group of "people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Wenger 2011, p. 1). In addition, we agree with Bowden and Marton (2004) that effective communities of practice are characterized as undefined *spaces of learning*: "the 'expert other'…does not necessarily 'know' the answers in a traditional sense, but rather is willing to support collaborative learning focused on the 'unknown future.' In other words, the 'influential other' takes learning…to spaces where the journey itself is unknown to everyone" (p. 295). This is the crux of making, as youth and an *expert other* work alongside one another in an *open* environment based on youth's interest(s) and continuous exploration in trying things out and making informed changes (Brahms and Crowley 2016; Petrich et al. 2013; Sheridan et al. 2014).

We acknowledge that learning through an ongoing process of participation is not the only valid perspective of learning and developing as a particular kind of person (e.g., scientist), as other perspectives have made valuable contributions to our understanding of teaching and learning. For example, the acquisition perspective considers learning as acquiring and accumulating basic units of knowledge (Sfard 1998). Students are viewed as empty vessels to be filled with facts and concepts (e.g., social efficiency; Kliebard 2004). Social constructivism is another perspective of learning in which students construct their own knowledge and understanding through building upon prior experiences and are actively building their ideas (Bruner 1985; Vygotsky 1978). However, within this paper we align with the participatory view of learning (Lave and Wenger 1991) as youth in our study are engaged in various skills common to professionals within STEM fields. Through engaging in various tinkering activities, it is expected that youth begin developing the knowledge and skills to becoming a member of the STEM community.

Methods

The context for this study was in an informal learning environment as opposed to a formal learning environment. Learning experiences outside of school are considered low-barrier entry points for triggering and maintaining youth's interests and perception of oneself as someone who uses and knows about STEM-related content and skills (Bell et al. 2012; Honey et al. 2014). Specifically, the study was conducted in partnership with a local museum that as part of their commitment to education provided an after-school program to elementary aged children in six local Title-I schools; schools where at least 40% of the student population is from low-income families (US Department of Education 2015). The purpose of the program, known as After School EdVentures (ASE), is to provide children with STEM-enriched activities and to support the state's academic standards in process and content for grades K-6. ASE is in each of the six elementary schools two times a year for a six-week period, once during the first half of the school year (August–December) and the other during the second half of the school year (January–May). More specifically, the program is split into two grade-based groups (K-2 and 3–6) who each engage in the STEM enriched activities twice a week for 45 min each day.

Each 6-week period is structured around a theme, or unit. In this study, the focus of the 6-week curriculum was electricity/circuitry; more specifically, utilizing products with tech-inspired, innovative material and cheap, easy-to-use tools (Martin and Panjwani 2016). Educators of the ASE program developed this unit for several reasons. First, it was strongly connected with upper elementary physical science content standards, as well as a strong connection to the process standards in design and engineering that builds iterative design and testing skills. Second, exploring circuits through new material (e.g., conductive tape) and techniques are a fun way to provide a connection to real world aspects of students' lives. Third, through creating and testing projects over and over again, students need to grapple with failure, which is an important part of science and should encourage project redesigns as opposed to giving up (Simpson and Maltese 2017). See Table 1 for a list of the daily activities. In general, youth were allowed to complete these activities individually or with a peer. Activities in which youth expected to take home a final product (e.g., Day 7) were typically performed on their own.

Two educators implemented the unit on electricity/circuitry to the youth in this study and identified broadly as facilitators. In addition, since the ASE program was part of the school district's after-school program, educators within this context also span to include three after-school employees who typically worked alongside youth during the making activities.

Table 1 Daily program activities

Day	Daily Activity
1	Introduction to Electricity & Circuitry General discussion on electricity (e.g., use of electricity, careers regarding electricity) and the difference between a closed circuit and an open circuit. Each student received a journal to be utilized throughout the program.
2	Introduction to Electricity & Circuitry Given a battery pack and an LED light, the intent was for students to explore the types of materials that are conductive (e.g., play-doh, human body) and non-conductive material (e.g., plastic, paper).
3	Introduction to & Exploration of littleBits Explore littleBits - how littleBits work and what littleBits do.
4	Flashlight using littleBits Construct a flashlight using littleBits, a paper towel tube, a clear cup, rubberbands, tape, and a diagram.
5	Build using LEGOs & littleBits Build something with the littleBits and LEGOs. The goal is to incorporate them together to build something that uses electricity.
6	Continuation: Build using LEGOs & littleBits Build something with the littleBits and LEGOs. The goal is to incorporate them together to build something that uses electricity.
7	Greeting Card with LED light Use conductive tape to make greeting cards that light up.
8	Greeting Card of own design with LED light Construct their own paper circuit using conductive tape and cardstock paper.
9	Introduction to sewing Practice threading a needle and sewing using conductive thread.
10	Bookmark Use conductive thread to make a bookmark that lights up.
11	Take apart an Electronic Device Explore the electronical components of a device.
12	Continuation: Take apart an Electronic Device Explore the electronical components of a device.

Note. littleBits are small, magnetic and pre-assembled circuit boards that promote "fullproof inventing" and "creativity" (littleBits Electronics Inc. 2017). For information on littleBits visit http://littlebits.cc/

Data Source

Prior to collecting data for this study, approval was gained from the Institutional Review Board. Therefore, all procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. After we informed parents and guardians about the study, youth were told about the study and provided daily assent by volunteering to wear chest-mounted GoPro cameras. They were not required to wear them every day and could take them off at any time during an activity. The point-of-view cameras allowed researchers to record youth's verbal communication and non-verbal interactions with objects while engaged in the daily activities. The justification of this approach is that GoPro cameras, as opposed to research observations and stationary or researcher-held cameras, brought our research team into each activity from each youth's perspective (Rennie and Johnston 2004). Additionally, GoPro cameras are equipped with a 170-degree angle lens that provided an expansive field of view even in close proximities.

The focus of this study was with youth in grades 3–6 (ages 8–12) because this group is at a critical time period for developing interest and engagement in STEM (Maltese et al. 2014). We accumulated a total of 54 videos from 11 participants across the 12-day unit, including between 2 to 9 videos each day and ranging in length from 20 to 45 min. We randomly selected two videos per day that were at least 30 min in length as we expected these videos to provide a high likelihood of capturing a student's engagement in the science and engineering practices from beginning to end of the activity. Based on these decisions, the data source for this study are 22 videos as the first day was not video-recorded, but used to introduce the study to youth and how to wear and handle the cameras appropriately.

Data Analysis

To address youth's engagement in science and engineering practices, we utilized the eight Science and Engineering Practices highlighted in the Next Generation Science Standards for grades K-12 in the USA (National Research Council [NRC] 2012), which include the following practices: (1) asking questions and defining problems, (2) developing and using models, (3) planning and carrying out investigations, (4) analyzing and interpreting data, (5) using mathematics and computational thinking, (6) constructing explanations and designing solutions, (7) engaging in argument from evidence, and (8) obtaining, evaluating, and communicating information. We utilized the NGSS practice skills because they are based on what professional scientists and engineers do in the field (NRC 2012). Similar practices of science education are also visible globally such as in countries across Europe (Education, Audiovisual and Culture Executive Agency 2011), China (Ministry of Education of the People's Republic of China 2011) and Australia (Australian Science Teachers Association n.d.). For example, one aim of the Australian Curriculum in Science is to ensure that students develop "an understanding of the nature of scientific inquiry and the ability to use a range of scientific inquiry methods, including questioning; planning and conducting experiments and investigations based on ethical principles; collecting and analysing data; evaluating results; and drawing critical, evidence-based conclusions" (Australian Curriculum, Assessment and Reporting Authority 2017). As another example, the Chinese Science Standards for middle grade students include "understanding scientific inquiry and improve inquiry skills" through six process standards including posing questions, constructing investigations, and presenting and communicating information.

We expected that the NGSS practice standards would not be representative of the science and engineering practices within this informal setting as these practices were developed for a formal setting (Falk et al. 2014). As argued by Falk et al. (2014), the NGSS practices do not “represent a complete set of practices nor a comprehensive view of what is involved in effective science learning experiences” (p. 2) as NGSS frames learning within formal learning settings. While some might argue that engaging youth in these practices is not necessarily an aim of informal science education programs, we contend that it is an explicit or implicit intention of every informal science program we have encountered and thus it is fair to evaluate programming for inclusion of this content. Therefore, in analyzing the data as aligned (or not) with these practices, we are able to consider how youth engage in these practices in an informal learning setting.

Utilizing video data from the ASE program the year before this study was conducted, the research team watched four videos to code for what we were observing and not observing regarding the eight practices, as well as additional practices of interest such as moments in which youth offered and/or provided assistance one to another. We met after each video to discuss and clarify terminology, provide evidence to support our observations, and refine our codes until consensus was met. Refer to Online Resource 1 for codes as aligned with the science and engineering practices. Across these videos that were selected, we did not observe engagement in all of the practices—notably we did not observe, engaging in argument from evidence (Practice 7), and obtaining, evaluating, and communicating information (Practice 8) in any of the videos. Hence, no codes were developed from this study regarding these two practices.

The intent in addressing the research question was not to count the number of instances each practice code was identified, but to gain a holistic picture of how and in what ways youth are engaged in the practices; in other words, what do these practices *look* like in this informal learning environment. Therefore, to ensure that we were capturing the full picture, two members of the research team coded every video using VideoAnt, a free, collaborative online video annotation tool developed by the University of Minnesota. Author 1 first coded each of the 22 videos. As a second viewing, Author 2 coded the 22 videos; adding additional codes, evidence, and comments, as well as indicating points of disagreements. Codes with no additional comments or disagreements were considered as agreement. In an attempt to evaluate and confirm this approach, Author 3 coded five of the 22 videos. This round of coding added very few new instances to any single video, but instead added more depth, in support of the existing codes from Author 1 and Author 2. Across the 22 videos, the research team coded 1707 instances as listed in Online Resource 1.

For each video, we constructed a flow chart to represent how the student was engaged in the eight practices as observed and coded for in the data. Doing so allowed us to consider how we might construct a general flow chart representative across the 22 videos with the goal of representing how the eight practices unfold sequentially and/or interconnect with one another (Bell et al. 2012; NRC 2012). For example, as stated by the National Research Council (2012, p. 3), “the practice of asking questions” may lead to the practice of “modeling” or “planning and carrying out an investigation,” which in turn may lead to “analyzing and interpreting data.” We wanted to determine if this type of flow manifested in these videos.

Results

To address our research question, the manner in which youth in this study are engaged in the eight NGSS practices, we begin with the general flow chart or a visual representation where the practices are sequenced and interconnected within this study. We then present evidence that describes each of these practices as aligned (or not) with the eight science and engineering practices within the Next Generation Science Standards (NRC 2012). In other words, we describe how we observed the eight practices unfolding (or not) in this particular informal setting and how engagement in one practice shaped another practice.

Within the context of making in the ASE program, a typical day began with a launch where the facilitator "hooked" youth into the activity. This was proceeded with the facilitator defining the task for the day, followed by youth engaging in the task. In most cases, the day concluded with youth completing the task and having a product to take home.

Practice 0: Active Listening and Communication At the beginning of each day, one of the facilitators connected the making-related activity to at least one of the previous day's activities and/or discussion. Although this is not a part of the science and engineering practices, we believe it is a foundational a priori practice that builds upon youth's prior experiences and prior knowledge. Additionally, youth are engaged in conversation as a scientist and/or engineer, as well as engaged in the practice of "listen[ing] effectively to decipher meaning, including knowledge, values, attitudes, and intentions" specific to the making and tinkering-based activity (Partnership for Twenty-First Century Learning [P21] 2017, p. 4). In this setting, the facilitator asked questions in which students were given an opportunity to respond, and in some instances, students capitalized on this opportunity to verbalize a personal connection and/or tell a relevant story. It was also evident in the data that the majority of scientific discussions occurred during this time period.

On Day 7, for example, the task was to utilize conductive copper tape, a battery, and a LED light to create a greeting card that lights up. The facilitator began with asking, "What kind of materials are conductors? And what do conductors do?" After a student responded that metal conducts electricity, the facilitator capitalized by further discussing and asking questions about other materials that are conductors (e.g., humans), as well as materials that are not good conductors (e.g., plastic). This information situated the day's task in activities and discussions from Day 1 and Day 2 when students utilized different material (e.g., wire, plastic, play-doh) to light up an LED light.

Practice 1: Asking Questions and Defining Problems In this study, the activities were defined as a task to complete by the end of the day or sometimes within two days. Youth were either guided in a step-by-step task or more often presented with a task that allowed for exploration and play, which may also be deemed as ill-structured problems (Jonassen et al. 2006). There were few, if any, activities that were posed as a problem to solve or as a scientific question to gather empirical evidence to explain some phenomenon (NRC 2012). The task and the amount of instruction provided seemed to shape the other practices that followed—what students engaged in (or not) and how students were engaged (or not). For example, on Day 10, the task was to sew with conductive thread to make a bookmark that would light up. Due to the novelty of sewing, the task was structured in a step-by-step manner, which limited the opportunity for youth to create their own circuits, as well as make mistakes and *test* their design. As another instance, on Day 8, the youth were challenged to make an LED greeting card designing their own closed circuit with copper tape. The nature of this task was open-ended and exploratory. The majority of students participating in this task were engaged in an iterative process of "testing" the circuit, troubleshooting potential problems, and making changes.

In addition to framing the task itself, this practice also includes asking questions or providing suggestions that would require an additional trial or further investigation, including conducting research of some kind. These questions are similar to those outlined in the eight practices as they can be "investigated with available resources," "arise from unexpected results," or "as a way to clarify and/or seek out additional information," to name a few (NRC 2013, p. 4). In our codes, we identified these as *Investigative Question by Student*, *Investigative Question by Facilitator*, and *Investigative Suggestion*. These questions and suggestions, however, may or may not have been investigated or taken up further by student or facilitator. As an example of an *Investigative Question by Facilitator*, as a student was putting together his LED greeting card, he was unsure of what to do next when a facilitator asked, "What else do you notice? Do you notice anything else about my greeting card?" After examining the exemplar greeting card, the student replied, "You put the tape on the other side." This investigative question was enough for the student to continue with the construction of his greeting card. In general, we noted how most of investigative questions and direct suggestions provided by a facilitator opened up opportunities for youth to explore further their design and/or object. As another instance, on Day 2 when students were exploring conductive and non-conductive materials, the youth were asked "Do you think it [LED] would work if we had a wire from this play-doh? You guys experiment with that and see."

On the other hand, when youth asked investigable questions, they were at times ignored by facilitators; these cases did not lead to an additional investigation and/or in-depth exploration. For example, as a student practiced how to sew, she directly asked the facilitator, "How do you sew pants?" This question could have been explored further in a number of different ways, but it was not. In other instances, investigable questions by a youth led to missed opportunities in the sense that a facilitator gave a direct response and/or took ownership of the design or object from the youth. On the last day, youth were taking apart electronic toys and putting pieces together to form a new object. One youth was interested in making a robot with her electronic pieces and in this instance, interested in making the upper body of the robot. "So, how do I do that?" As opposed to allowing this particular youth to explore this on her own, the facilitator stated, "What I would like for you to do is just lay down some pieces on here and I'll glue them." Also noted in this statement is limiting youth's access to material as the facilitator will glue the pieces down.

Practice 2: Developing and Using Models In the context of making in the ASE program, we found little evidence to support this practice. This practice is noted as "construction of object." In most instances, regardless of whether the task was procedural or more exploratory in nature, youth were rarely provided opportunities to brainstorm or sketch ideas of how they would accomplish the task or "play" with the material with some goal in mind. It was more likely that students constructed, de-constructed or explored the object itself as opposed to sketching a model in their journal or constructing a physical scale model (NRC 2012). However, one exception was observed on Day 8 when the facilitator encouraged youth to "design your own circuit inside your journal first" before proceeding to making your own greeting card that would illuminate when the circuit was closed. Yet the majority of students did not engage in this practice as they followed the pattern provided by facilitators from the previous day. Within this setting, journals were more often used at the end of the day to document what students did such as taping in a diagram or making a list of conductive and non-conductive materials. At this point, however, youth in this study were resistant and adding to the journals seemed more of a chore. We saw no examples of youth building prototypes with cardboard for example during these sessions.

Practice 3: Planning and Carrying out Investigations Students in this setting made "planning" statements (i.e., verbal statements) while engaged in the task, which allowed us insights into their next steps. In the process of taking apart an electronic device, one student reported the following:

> But actually I want to make a robot because if I make a project with this stuff I won't have enough to make a robot. . .So I'm going to make a little robot today. ... I want it to be on wheels. But I want it to climb and have feet and wheels and stuff like that.

The student continued to plan how to do this and used materials from the electronic device to construct a remote control for the robot. However, it is important to note that these statements were not common. It is plausible that youth were continuously planning their next steps, but chose not to verbalize them. As another instance from Day 4, "I just need to keep getting more of these [LEGO pieces]. All I have to do is keep getting more of these because I have to keep extending."

Yet, as delineated in Practice 3, we observed many instances where students carried out investigations that we coded as "trials." Depending on the task, students "tested" whether the initial and ongoing construction of their object was a success or a failure. Trials, in most instances, led to one of the following: (1) immediate design change, (2) troubleshooting (Practice 4) followed by design change; or (3) verbal interactions (Practice 1) followed by design change. Here, the focus is on how trials led to immediate design changes as the other two outcomes are discussed within their respective practices. In making immediate design changes, it was frequently not apparent *why* youth made any design changes other than the trial was a failure and/or it was part of the exploration—figuring out what works and what does not work. The first instance is from Day 2 where youth explored the type of materials that make an LED light functional. Within 1 min, a student conducted three trials and two design changes: (1) tested LED light in play-doh—failed, (2) added a wire to play-doh, (3) tested LED light—failed, (4) turned LED light around, (5) tested LED light—worked. Yet the student continued designing the object as he noted, "This is barely working."

A second instance is from Day 7. The task was to follow pre-defined steps to make an LED-illuminated greeting card. After re-taping a battery that fell off the card, a student tested his design and it was not successful. He added more tape over the battery, which blocked the flow of current making the next trial a failure. He next added more tape on top of the tape holding down the legs of the light. The next trial was a failure because the previous issue was not resolved. Such instances of immediate design changes after trials were common; yet, it was not apparent if these changes were informed based on observational data and prior experiences or if these changes were made without much thought. It often seemed that these were not changes based on much, if any, evaluation and reflection.

The presence or absence of trials was typically dependent on the task for the day. Tasks that were structured in a step-by-step nature such as learning about and practicing sewing skills on Day 9 or constructing a flashlight given a diagram to follow on Day 4 seemed to eliminate the potential for youth to conduct trials. Additionally, trials were not evident the last 2 days when youth were taking apart electronic devices as there was nothing to "test." As a research team, we believe there is value in taking devices apart as youth are able to see how objects are put together and gain an understanding of how objects work. We also acknowledge that conducting trials and design iterations are dependent on the student as they may frequently ask for help from facilitators or may choose to stop taking part in the task altogether.

Practice 4: Analyzing and Interpreting Data Active participation in analyzing and interpreting data was difficult to observe in this setting as students did not document their steps, ideas, or discoveries while engaging in tasks. We want to assume that students were collecting, analyzing, and interpreting data to make informed decisions when they made changes to their design; however, we saw little evidence to support this. In our video data set, we observed a few instances after a trial when students appeared to examine why their design was or was not working. In exploring littleBits on Day 3, a student “tests” the circuit built. Half of the circuit worked, while another half of the circuit did not because in this particular instance, there was an input Bit (on-off button) in the middle of the circuit that had to be pushed to complete the circut. We see the student looking at this input Bit; troubleshooting the connection and stating: “Maybe it's this way. May its upside down. Maybe...uhm. Like this. Turn it." Once reattached, and without an additional “test,” the student continued exploring by adding additional littleBits and testing the design.

Practice 5: Using Mathematics and Computational Thinking Mathematical thinking was evident in a few of the videos, but not to apply these methods to analyze data, compare design solutions, or in describing their observations (NRC 2012). Mathematics was utilized by students in two ways. First, students used mathematics as a tool, mostly in the form of indirect measurement. In building a motorized car using LEGOs and littleBits, we observed a student physically compare the lengths of LEGOs to make sure they were the same. Second, the students participated in counting the number of objects. For example, “We have seven screws,” or “I got 18 [buttons]. My favorite number!” In another instance, a student counted the number of studs of a LEGO piece on his army base to decide the size of LEGO piece to add on top. “I need four.” In all instances in this study, mathematics was not something intentionally planned for by facilitators or even apparent in any of the questions asked to students, but was occasionally engaged in by students during their activities.

Practice 6: Constructing Explanations and Designing Solutions We found evidence of student’s constructing explanations most often in response to a question posed by a facilitator or assistant, which highlights the importance of asking “good” questions. In taking apart a keyboard, a student was asked, “So the circuit board leads to the battery pack, right? And can you tell me why you have a wire on each side?” The student responded, “There’s one that’s positive and another one that’s not positive.” This explanation suggests that the student gained some understanding over the course of the program and applied “standard explanations they learn about from their teachers or reading” (NRC 2012, p. 11). In another example, a student constructed an explanation based on his exploration and observations when deciding the types of material that would and would not illuminate a LED light. As he twists the legs of the LED light, the light flickers on and off. He first verbalized, “All I have to do is twist it.” But then he constructed the following explanation, “It’s using my finger. That’s why [it works].” When he holds the legs of the LED light with his fingers, it’s breaking this short circuit and making a complete circuit through his body.

This practice also includes designing solutions to solve problems. In this context, we use “design solution” loosely as the tasks were not posed as problems to solve (see Practice 1). However, a design solution is a logical conclusion for “interpreting data” because students are using the observational data and evidence they gathered from a trial to make changes to their objects, resulting in designs that meet their expectations for what the objects should look like or do. Constructing a flashlight by utilizing a diagram is an obvious example of a task with a clear design solution. On the other hand, constructing a motorized car using littleBits and LEGOs, one student conducted many trials and made informed design changes to come to a solution that matched her or his conception of what the car should look like and what the car should do, such as “drive” in a straight line as opposed to in a circle.

Practice 7: Engaging in Argument from Evidence In this study, youth did not engage in argumentation from evidence. Argumentation is a process involving the use of evidence to construct a claim aimed at convincing others of the acceptability of the claim (Bricker and Bell 2008). In this setting, having the students make a verbal claim resulting from their “data” was rare considering that much of their construction and testing was done in a non-verbal manner. When students did make a verbal claim about their project, such as the example above of the child explaining that the LED light was using his finger as a conductor, students were never asked to support these explanations with observations or relevant scientific concepts to provide convincing evidence for their claims, as is called for in creating an argument (Bricker and Bell 2008). In this example, the student could have been pushed to create an argument if a facilitator asked “How do you know it is using your finger?” or “How can your body acts as a conductor?” Because the focus of the program was more on open exploration, these sorts of questions to instigate argumentation were rarely, if ever, posed.

Practice 8: Obtaining, Evaluating, and Communicating Information Our data yielded no evidence of youth reading and interpreting scientific and technical grade-appropriate texts or communicating information or designs in oral or written form (NRC 2012). In other words, youth in this study did not engage in research, read scientific literature, or formally “present” final models or products to one another. Based on our observations and conversations with the program designers, we know that conducting of research was part of the program design. While there were some potential opportunities for presentations to occur, we hypothesize that educators did not feel this was feasible due to the structure of the after-school program; particularly, the 45-min time period and with new tasks being defined every 1–2 days.

Discussion

With this study, we hope to provide a glimpse into what science and engineering practices might look like in an afterschool informal setting for youth focused on tinkering within a STEM-enriched unit. We acknowledge that the goals of informal science education and formal science education as described in the NGSS standards are not necessarily meant to be the same (Falk et al. 2014); and therefore, enactment of practice standards will *look* different across these contexts. For example, in a classroom, constructing an explanation is often completed on an exam or lab report, simplifying the process for educators or researchers wanting to assess this standard. In an informal context, say a tinkering activity in a museum, the construction of an explanation might involve an educator asking a youth to describe a design choice she made, where the response is evaluated in situ without the help of standards or a rubric. We do not mean to imply that either case is more valuable or more rigorous, just that the event and the evaluation may take rather different forms. However, we do think that science and engineering practices are happening in these making activities and using something like the NGSS practices as a way to capture them can yield fruitful results and bridge a conversational gap between formal and informal educators.

As indicated in our results, many of the NGSS standards may be enacted in informal making settings by youth and facilitators, they just look different to what is typically enacted in formal settings. This general sequence is visually represented in Fig. 1, which within our data varied slightly by day and by student.

We argue that Practice 1 is apparent in our data but more often the task was framed as either procedural or exploratory in nature (e.g., littleBits) as opposed to a problem to solve or a laboratory experiment to complete. Although some may argue that framing the task as procedural is not inherent in the notion of making, Blikstein and Worsley (2017) noted how such guided facilitation is warranted for novice maker and tinkerers. When absent, novices tend to feel lost and frustrated, and by the end of the iterative process, tend to experience a loss of self-esteem. Kapur (2016) too argued that unguided problem solving and inquiry more often lead to unproductive failures with few benefits for learning new skills and knowledge. In Practice 2, youth in this study often began construction of their object void of building a prototype, brainstorming ideas, or sketching drawings in a journal. In Practice 3, youth did not plan and carry out a formal investigation or procedure in regards to the task, but they verbalized statements regarding what they planned to do next through exploration and play. Similarly, youth conducted many trials as they "tested" their designs. Here, the tests were carried out frequently within the design process to explore and/or make ongoing changes to constructing a final object (e.g., greeting card that lights up) as opposed to collecting data for an experiment. From this, it may be surmised that youth were engaged in analyzing and interpreting *data*, which is endemic in Practice 4. Yet, within the context of this informal making program, the data analysis that youth engaged in was embedded within their explorations and innovations. Lastly, in Practice 6, youth devised a "solution" that met their expectations or those set forth by facilitators. In other words, the youth were able to construct an object that performed as expected and/or defined through the launching of the task. We contend that, despite the tinkering program being part of an afterschool program, youth in this study were engaged in various science and engineering practices common to professionals in

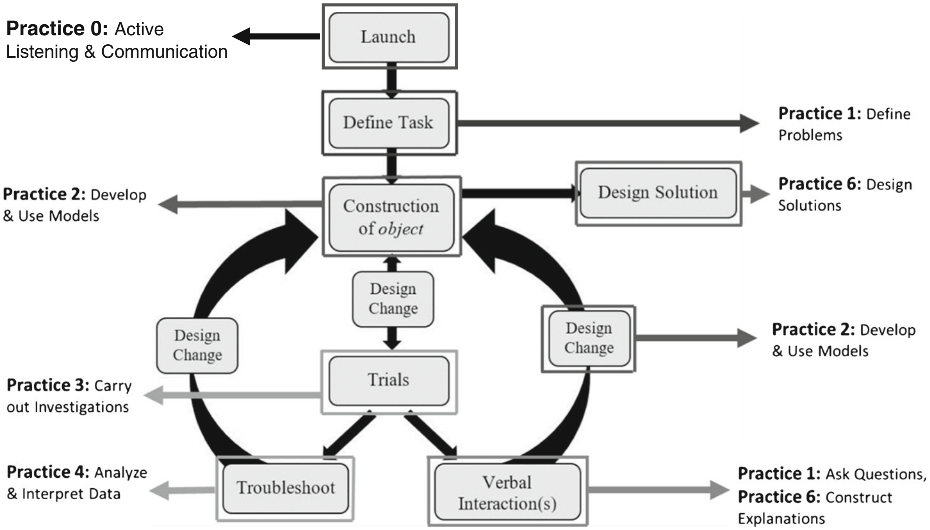

Fig. 1 Working model of student engagement in science and engineering practices in an informal learning environment

these respective fields, hence developing the practices and skills to becoming a member of the STEM community (Lave 1991; Lave and Wenger 1991).

The most significant contribution of this work is that it is the first research where data from individuals involved in making and tinkering was coded for the occurrence of the NGSS science and engineering practices. Most extant research on youth within afterschool STEM programs documents benefits including increased interest in STEM, attitudes toward the fields of science and engineering, efficacy for *doing* STEM, and cognitive and social skills (e.g., Krishnamurthi et al. 2013; MacEwan 2013). While some researchers have looked at engagement of youth in scientific, engineering or mathematical practices, these studies predate NGSS and did not specifically look across a range of science and engineering practices.

Second, based on our results, we created a model for how these practices are enacted in a making context. This model, unlike previous research on making and tinkering (e.g., Kim and Zimmerman 2017), observed youth's engagement among eight practices as opposed to one or two practices. In Fig. 1, enactment of science and engineering practices is a non-linear *messy* process in which particular practices (or lack thereof) shape and inform one another. Within our data, this typically occurred as youth *tested* their objects or products and made informed and/or uninformed design changes. As opposed to other processes that may emphasize "a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants" (NRC 2012, p. 202), we contend that within our study, youth were engaged in an unsystematic, playful, iterative approach to design. It seemed as if decisions made through engagement with tinkering-related tasks were more often not intentional or based on conclusions from troubleshooting issues; yet, as illustrated in Fig. 1, youth were still involved within an iterative approach to design. Youth were engaged in these practices without them being an explicit part of the program, unlike other studies where scientific process skills were a part of the formal teaching program (e.g., Aktamis and Ergin 2008). Our interpretation is that youth in this study were engaged in *experimental* play (Dougherty 2013) and "*disguised learning*" (MacEwan 2013), while developing some of the practices and skills of scientists and engineers (NRC 2012).

On the other hand, youth in this setting were provided minimal opportunities to engage in all eight practices: particularly, mathematics and computational thinking (i.e., Practice 5), argumentation from evidence (i.e., Practice 7), and obtaining, evaluating, and communicating information (i.e., Practice 8). This is not of great concern as youth were *acting* like scientists and engineers within this study. Engaging youth in these practices was not a high-level goal of the ASE program, but we are of the opinion that afterschool programs have an opportunity to engage youth in these practices as youth may not have an opportunity to engage in these practices through formal schooling or other informal settings such as home environments. On balance, we do not want engagement in tinkering-related activities to become too structured or formulaic, but a natural part of the process through various instructional methods. For example, computational thinking (Practice 5) can be promoted through framing investigations or tasks that involve simulations, programming robotics and other devices, and/or computer game design (e.g., Lee et al. 2011).

To promote argumentation (Practice 7), facilitators are encouraged to build this practice of critique around art critiques (e.g., Bartel 2012) and collaborative meaning-making discussions (Kim and Zimmerman 2017) as opposed to reasoning argumentation based on evidence and/or interpretation of facts, other's explanations and procedures, and/or solution to a problem (NRC 2013). This practice can be promoted through questions posed during the process (see Bartel 2012 for examples) or at the completion of the task. If the tinkering tasks are completed on a daily basis, facilitators can encourage argumentation through a final presentation in which youth present their favorite product over the course of the program. Practice 8, as noted as a practice in NGSS (NRC 2013), includes reading, synthesizing, and communicating scientific and/or technical information from multiple resources. We encourage this practice through encouraging youth to research personal interests, ideas, and curiosities. For instance, when youth pose an investigative question (e.g., "How do you sew pants?"), lead them to useful websites, books, videos, and/or audio files to gather information. In other words, engage students as researchers.

Further, we contend that this work highlights what may be termed *missed opportunities*; opportunities for educators to engage youth in further discussion and exploration across most of the practices, but do not capitalize on these moments. We want to be abundantly clear here—we completely understand how educators involved in programming like this have many issues to consider when designing and implementing activities for youth. We do not mean for missed opportunities to be a major critique of their practice, but rather something that might be addressed in ideal circumstances where educators can be everywhere and do everything that each child needs to get the best learning experience possible. To be concrete, we present an example of how we think engagement in the practices might be improved with only moderate shifts in practice. As a research team, we encourage the use of journaling prior to and while carrying out an investigation or prototyping as it serves as a personal and creative outlet for ideas, sketches, observational notes, and reflective insights (Pappas and Pappas 2003; Schmidt 2013). The use of documentation was minimal throughout the activities we observed. Youth often engaged in making a journal at the beginning stages of their participation in these activities, setting the stage for some amount of documentation through the rest of the program. However, there were minimal instances when the instructors suggested youth use these tools to document their planning, to collect data at trial/data stages and to keep track of revisions. While documentation does take time, this missed opportunity could be addressed by suggesting a small bit of note-taking or summarizing to youth throughout the program. We think the most beneficial part of this practice, beyond being key to advancement of science and engineering, is giving a common reference around which educators and youth can discuss ideas for planning, building and revision.

Our results suggest that the framing of the learning task (i.e., step-by-step recipe versus exploratory) did not lead to differences in engagement with the eight science and engineering practices, but rather a multitude of factors were influential including the novelty of material and tools, interaction with facilitators and peers, and youth's persistence or learned helplessness. As one example, the construction of light-up greeting cards was procedural or presented as steps to complete. Yet, engagement in the practices of professional scientists and engineers with the novel material (e.g., conductive tape, battery) varied across two youth whose videos we analyzed. One youth tended to wait on instruction from facilitators throughout the construction of the greeting card and, therefore, did not engage in the core aspects of Fig. 1, namely conducting trials and making design changes. These were typically engaged in by the facilitator as the youth consistently asked for help. The other youth did not sit idle for instructions, but rather worked ahead and had several experiences with failure as many of the trials did not work appropriately. This youth tended to make design changes based on troubleshooting of issues as well.

Lastly, as noted by Falk et al. (2014), there is more to *doing science* than the eight science and engineering practices (NRC 2012). Our findings support that claim with instances of what we consider part of the process of enacting practices common to scientists and engineers. However, most frequently these instances are not *explicitly* stated within the parameters of standards. For example, we observed instances where failures within students' designs and explorations led to *informed* changes and continuation of play. Similar to that of STEM professionals, these failures were not an end to their exploration and design solution as rarely did youth in this study quit, but instead they continued to persist until reaching a point of success (Simpson and Maltese 2017). Based on this, youth experienced similar situations as professionals in the field, as well as *acting* or responding similar to individuals in STEM (Lave 1991). Furthermore, we contend that through these failures, youth created new and worthwhile design solutions that demonstrated creative solutions; therefore, engaging in practices of creativity and imagination deemed essential for future work environments (Meador 2003, 2017 p. 21).

Conclusions

There are several limitations to acknowledge as the results are not generalizable across informal learning contexts including informal learning contexts with a specific focus on making-related activities with youth. One, this study was conducted in one after-school program in a Title 1 school located in central US. Two, the grade band of our youth participants was 3–6, which excludes those engaged in making-related activities in afterschool programs outside of this range. As such, the results from this study are not widely generalizable. However, we contend that the results from this study are *grounded generalizations* (Eisenhart 2009) and build upon the argument of Falk et al. (2014). Future research studies across informal learning context with youth will aid in refining the current working model (Fig. 1) of how youth are engaged in science and engineering practices and will help policymakers, formal and informal educators, administrators, and community leaders to make an informed decision regarding the implementation of making to address the learning and teaching of science and engineering practice skills. In addition, future research should examine the ways youth engage with mathematical and technological practice skills, with a cross-analysis of the manner in which the practice standards within each discipline informs one another. One final limitation is the lack of member checking with our participants. Hence, a similar study could include stimulated recall interviews with youth as a means to gain additional insight regarding their perception of engagement (or not) in practices common to scientists and engineers.

The results from this study also highlight the importance of the task, as well as the material and role of facilitators who engage and interact with youth within a making context. For example, the questions posed (or not) may lead to additional practices such as developing and planning an investigation (Practice 3) or conducting research (Practice 8). As another example, the construction of light-up greeting cards was procedural or presented as steps to complete. Yet, engagement in the practices of professional scientists and engineers with the novel material (e.g., conductive tape, battery) varied across two youth, whose videos we analyzed. Future research could explore the interactions between facilitators and youth, or even among the youth as peer collaborators, influence engagement within the various practices of STEM professionals. Additional studies can continue to examine the maker phenomenon as a way for informal and formal science educators to collaborate and improve their teaching practices, as well as consider how the design and implementation of making-related tasks may act as a potential bridge between the goals and standards of informal and formal sectors.

Compliance with Ethical Standards This study was approved through the Institutional Review Board. Therefore, all procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in this study. Additionally, the authors declare that they have no conflict of interest.

Conflict of Interest The authors declare that they have no conflict of interest.

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