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Maker-Centered Learning in STEM: A Case Study of a Chemistry Teacher's Lived Experience

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Researchers and educators are exploring approaches to integrate the maker movement in educational spaces such as STEM subjects to explore the importance of artifact creation through physical and digital tools. They are investigating strategies and models of its application in the classroom. However, research is needed to understand the lived experiences of teachers implementing maker-centered learning activities in the classrooms. Addressing this gap, this study employed a phenomenological method to document the struggles and breakthroughs of a chemistry teacher in maker-centered learning. As a qualitative case study, it provided an in-depth understanding of her lived experience, explaining the affordances and constraints of the implementation of a maker-centered learning framework. This study highlights the significance of adopting maker-centered learning in the STEM curriculum. It suggests that maker-centered learning activities can promote engaging opportunities for students in STEM subjects by enabling them to acquire skills to engage in the physical creation of artifacts. It was evident in the study that a teacher's past experiences, education, and professional development can play an important role in shaping their teaching practices and pedagogical dispositions. The purpose of this research is to add empirical qualitative research to further support the benefits of maker-centered learning in educational spaces.

Keywords: lived experience, maker-centered learning, science teacher professional development, stem education

INTRODUCTION

Maker-centered learning has emerged as an inclusive term to capture the role making plays in educational institutions (Clapp, Ross, Ryan, & Tishman, 2016; Scharon, Phillips, & Jones-Davis, 2024). Martin (2015) explains that the advent of the maker

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movement stems from the need to engage in the process of creation through digital and physical mediums supported through digital fabrication, online networks, and the prevalence of learning via the Internet. Research (Halverson & Sheridan, 2014; Oliver, 2016; Scharon, Phillips, & Jones-Davis, 2024) indicates the maker movement has garnered interest from stakeholders in educational institutions because of its perceived connection to science, technology, engineering, and math (STEM) as well as its ability to encourage students to take ownership of their learning through informal learning environments. Educational researchers (Bevan et al., 2014; Douglass, 2023; Hsu, Baldwin, & Ching, 2017; Martin, 2015) suggest that maker-centered learning activities may attract greater numbers of students to pursue opportunities in STEM content areas. According to Peppler and Bender (2013), this connection has been formed due to the accessibility for students to create numerous educational objects using digital and physical tools, which is evident in informal learning spaces, and the availability of the tools and technical knowledge required for artifact creation.

Makerspaces are spaces whereby learners actively engage in the physical creation of objects through the assistance and support of tools such as digital technology. They thereby become the embodiment of the maker movement principles, reflecting the desired and preferred learning environment. The ideal learning environment for the maker movement is an informal space equipped with the tools necessary for creating the desired artifacts and allows for creative expression of learning (Soomro, Casakin, Nanjappan, & Georgiev, 2023). The maker movement’s strong ties to constructivism and constructionism (Ackermann, 2001) allows both learner and leader the opportunity to embark on processes that involves representations of the learner’s thinking and doing (Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe, & Owens, 2014). The relationship between the mind (constructivism) and body (construction) allows for the exploration of the importance of both cognitive and physical aspects in STEM learning and other subject areas.

Finding engaging methods to motivate student learning is imperative for knowledge acquisition (Astiningsih & Partana, 2020). Teachers are on the frontline of the maker movement in education, and they need to have experiences that support and facilitate maker-centered learning practices (Clapp et al., 2016; Hughes, Robb, Hagerman, Laffier, & Cotnam-Kappel, 2022). Empowering teachers to gain the knowledge to conceptualize the maker movement and the makerspace itself will allow its acceptance in the classroom culture (Oliver, 2016). Maker-centered learning has the potential to enhance learning in STEM subject matter such as sciences and physics through creation (Tabarés, & Boni, 2023). However, there is a need for teachers' professional development in the integration of maker-centered learning into their curriculum (Clapp et al., 2016; Cohen, 2017). Research (Paganelli, Cribbs, Huang, Pereira, Huss, Chandler, & Paganelli, 2017; Oliver, 2016) suggests maker-centered knowledge development is crucial for teacher participation in incorporating the concepts and principles of making into their curriculum. Understanding teachers’ implementation and integration of makerspace activities into the curriculum calls for the examination of their lived experiences (Aghaei, Bavali, & Behjat, 2020; Bobst Mangum, & Wolf, 2017), which entails a close analysis of their challenges and successes throughout maker-space learning.

Critical evaluation of programs and classes that apply and promote maker movement principles could afford teachers a better understanding of the maker movement. There is a need for further research on the teacher's experience with maker-centered learning (Hughes et al., 2022). While there is extensive literature that describes the conceptual knowledge appropriated by the teachers, few studies examined the actual incorporation of maker-centered learning in a classroom. The existence of empirical studies has the potential to foster mainstream acceptance and incorporation of maker-centered learning in educational institutions. A recent study conducted by Stewart, Yuan, Kale, Valentine, and McCartney (2023) used analysis of variance (ANOVA) in student survey questions as well as analysis of covariance (ANCOVA) in student writing to show “quantitative evidence of the benefits of makerspace” (p. 138), which shows the importance and necessity to incorporate quantitative research in the maker movement (authors, 2020).

The purpose of the current study was to address this gap in the literature by focusing on the lived experience of a teacher incorporating maker-centered learning into her praxis. A phenomenological lens and a case study were deployed to develop an in-depth understanding of the lived experience, or “lifeworld” of the participant while she attempted to integrate a maker-centered learning framework into her curriculum (Clapp et al., 2016; Dahlberg, Dahlberg, & Nyström, 2008; Dougherty, 2016; Hatch, 2013; Thomas, 2014; Stewart et al., 2023). The focus on one teacher’s integration of a maker-centered curriculum allowed for the documentation of “things themselves” and the exploration of educational processes through pre-reflective and reflective moments (Husserl, 2001, p.168). This study aims to enhance learning in STEM subjects by gaining insight into the process of integrating maker-centered learning in formal educational institutions through close observation and detailed documentation of an individual chemistry teacher’s experiences and changing routines (Gallego-Sánchez, González, & Gavilán-Izquierdo, 2022).

Theoretical Framework

The maker movement, a relatively new term established in 2006 by Dale Dougherty (2016), is conceptualized as a vehicle to carry STEM learning into the classroom. Several studies examined the positive impact of the maker movement on STEM subject matter (Tofel-Grehl, Fields, Searle, Maahs-Fladung, Feldon, Gu., & Sun, 2017; Wright, Shaw, Gaidos, Lyman, & Sorey, 2018; Scharon et al., 2024; Tabarés et al., 2023). These studies align the ideals of the maker movement with John Dewey (1929) research, as both Dewey and the supporters of the maker movement see education as a vehicle for the training of students to have full command of their potential capabilities.

Wright, Shaw, Gaidos, Lyman, and Sorey (2018) examined the experience of incorporating a National Science Resource Center (NSRC) curriculum on motion and design with engineering design principles. A structured hands-on activity centered on the creation of a propeller-powered car was utilized to illustrate the engineering design cycle including defining a problem, researching and considering multiple possible solutions, and rigorously generating, testing, and optimizing solutions to the best possible design (Wright et al., 2018). The focus of this experience was the construction of a propeller car with a 3D-printed propeller.

The possibility of attracting more students to the STEM fields through the maker movement was investigated by Tofel-Grehl et al. (2017). Their research used a quasi-experimental research design to assess eighth-grade students' motivation in their science class. The researchers also explored the students' change in attitude towards science over time, interest in a scientific career increased, and student learning outcomes using an e-textile unit and a traditional unit with the eighth-grade students (Lindstrom, Thompson, & Schmidt-Crawford, 2017; Vossoughi, Hooper, & Escudé, 2016). Litts, Kafai, Lui, Walker, and Widman (2017) examined the understanding of functional circuitry and software design in high school contexts through textiles. They used a pre- and post-experimental design to analyze students' abilities to read codable circuit designs and remix functional codes for controlling circuits. The findings supported a substantial increase in student knowledge and design of the circuitry, which indicated their grasp of the interconnectedness of circuit design and coding.

Clapp et al. (2016) offer "Thinking Routines" to the maker movement conversation which focuses on ways to empower students through focused inquiry, design, and construction. The different Thinking Routines allowed students to focus on an object, issue, or idea to analyze and alter their perceptions while trying to create a different way to solve the problem posed. These ideas are supported and extended by Scharon et al. (2024) as they incorporated social and emotional competencies necessary for an inventive mind. Both build on the connections between constructivism and constructionism, which are foundational principles in the maker movement. Constructivism is a learning theory that posits the learner in the center of knowledge creation (Ackermann, 2001). From this perspective, the learner's experience and interaction impact knowledge creation, and not the curriculum, the teacher, or the learning environment (Bobst et al., 2017; Lev Vygotsky, 1978). Seymour Papert (1991) implemented a concrete experience alongside the ideals of learning through the process eschewed through constructivism (Papert, 1991). Papert (1991) placed students as active participants in knowledge creation. The teacher is seen as a knowledge facilitator rather than a didactic dictator found in traditional classrooms.

Constructivist and constructionist principles align with the maker movement and the maker-centered curriculum as they facilitate learning through the conceptualization and creation of physical and digital artifacts. They are concerned with the process of how a student achieves their learning goal. However, there is a significant lack of empirical data that explores and defines the ways the maker movement practically goes about changing educational culture through lived experiences (Oliver, 2015; Mersand, 2021; Rouse & Rouse, 2022). There is a need to understand the lived experiences of STEM teachers implementing and incorporating maker-space activities in their curriculum (Bobst et al., 2017). Gaining insight into the process could facilitate learning in STEM subjects. Studies involving students do not conclusively show evidence that the maker movement fulfills its claims to drastically change educational results and culture. According to Dougherty (2016), the maker movement is viewed as a learning technique, or merely another hands-on learning activity without understanding the implications of the maker movement.

Purpose

The maker-centered learning framework was developed to establish a different ontological and epistemological perspective of the maker movement (Clapp et al., 2016). The characteristics of this framework include community, process, and environment. They expanded what it means to be a maker beyond the beliefs typically associated with the banner term 'maker movement', and subsequently the space, termed maker space. These components take into consideration the learner and allow for the overarching idea of "sensitivity to design", which emphasizes the functionality of objects being created. The current study draws on this framework and builds on the existing literature review to examine the lived experiences of a chemistry teacher. The following research questions guided the study:

- What are the perceived benefits and challenges of incorporating maker-centered learning activities in STEM, as experienced by a chemistry teacher?
- In what ways does the teacher's praxis reflect the maker-centered learning principles and characteristics, if any, in instruction?

METHOD

Research Design

The study recorded and examined the experience of a high school chemistry teacher's incorporation of the maker-centered learning framework into the chemistry curriculum using a phenomenological method. The context of the research fell within the parameters of a case study as the aim was to capture "an in-depth description and analysis of a bounded system" (Merriam, & Tisdell, 2016). Considering that a case study is defined by the unit of analysis, and not the topic of investigation, the current study focused on one high school chemistry teacher operating within a bounded system as she began to develop and implement maker-centered learning lesson plans. Creswell (as cited in Merriam & Tisdell, 2016) argues that case study research is a qualitative approach that explores a case or multiple cases over time, through detailed, in-depth data collection involving multiple sources of information and reports a case description and case-based themes.

The study captured the teacher's lived experience through understanding and interacting with the teacher's epistemological and ontological creation attached to maker-centered learning. It employed a qualitative research method to ascertain the meanings brought forth by the lived experience that the chemistry teacher undergoes with maker-centered learning. Using a phenomenological approach the aim was to gain insight into the induction of a new praxis and maker-centered learning. The rationale behind adopting a phenomenological approach and a single-case study was to analyze one participant and their context to gain a deeper understanding of maker-centered learning and the transference of knowledge to their classroom and attitude (Yin, 2018; Wahyudiati, Rohaeti, Irwanto, Wiyarsi, & Sumardi, 2020). This approach aims to gain insight into the teacher's perspectives regarding the learning experience and how they were perceived, interpreted, and described through personal thoughts, emotions, and feelings (Clapp et al., 2016). The process of recording lived experiences is referred to as "the

Lived Experience Description" (LED), a term coined by van Manen (2017) to define the empirical approach that uses activities that explore the range and varieties of pre-predicated experiences.

Participant

Educational institutions are eager about the possibilities afforded by and through the maker movement (Sang & Simpson, 2019). This study explored the complexities of a teacher integrating maker-centered learning into her praxis. The participant was a thirty-seven-year teaching veteran Janice (pseudonym) employed by an all-girls independent private school located in the Southeastern part of the United States. The majority of her teaching experience had occurred at her current school with short stints at the collegiate level. She has a bachelor's and master's degree in chemistry and participated in a maker movement professional development class that was offered in the spring of 2018. The professional development experience took place in a commercial maker space with seven other teachers from her school. She also was the teaching advisor for a Makerspace Summer Enrichment program that was organized through her school and occurred in the same commercial maker space. During the research study, she taught four different sections of 10th-grade chemistry at the high school. Her background knowledge and experience helped in the formation of the maker-centered school curriculum.

Data Collection

The lived experience of the teachers in this case study was captured through interviews, class observations as well as an analysis of her curriculum, the science curriculum, and the larger school curriculum. Multiple interviews were conducted over the course of the term, transcribed and analyzed. Meaning units were assigned to specific ideas expressed in the interviews (van Manen, 2015). The meaning units created by the participant were compared with the theoretical framework for comparison and alignment which allowed for the development of epistemology, acknowledging the teacher's experience with maker-centered learning. The interpretation of this data was conducted alongside the acknowledgment of the researcher's own positionality. The following table summarizes the data collection process:

Table 1
Data collection process

Method	Procedure	Materials
Artifact Collection	Content analysis	School Curriculum, Science Curriculum, Chemistry Curriculum
Preliminary Interviews	In-person interviews	Semi-structured interview questions
Observations	In class observations	Contact Summary Form that summarized observed activities
Debriefing Interviews	In-person interviews with the teacher directly after class	Maker-centered learning: looking closely, exploring complexity, and finding opportunity
Exit Interview	In-person interview	Open-ended interview questions for final thoughts that may had been missed during the interview process

Data Analysis

A hermeneutic understanding of the experience as the participant engaged in implementing maker-centered learning was built through the analysis of the data. The analysis of curriculum materials was conducted with the purpose of building a historical context within which the participant was operating. Prior to observations and interviews, the school curriculum, science curriculum, and chemistry curriculum were analyzed. The procedures used to construct knowledge were content and heuristic analysis to gain a deeper understanding of the importance of the curriculum within the school and in the teacher's classroom. Applying content analysis, the curriculum was organized into themes and categories to help understand the place of the maker-centered framework in the school structure.

The interview process allowed the teacher to communicate her educational lived experiences as well as her work experiences. The interview was conducted in a phenomenological manner whereby the researcher bracketed their perceptions to allow the teacher's pre-predicated conscious thoughts to come forth and capture the Lived Experience Descriptions (LEDs). The interview questions included information gathering regarding the teacher's professional development experience. The teacher was interviewed nineteen times. During this process, memos were created after each interview as well as after each observation to establish a reflective component of the research study.

FINDINGS

Janice's personal and professional history provided insights into her maker-centered learning experiences and her pedagogical approaches to teaching. The findings illuminate Janince's lifeworld and her pedagogical moments as a chemistry teacher. They emphasize the importance of considering a teacher's lived experiences to understand the application of maker space in the classroom. The hermeneutic circle of interview and observation processes allowed for a deeper understanding of pedagogical moments or instances of pedagogical situations through a phenomenological research approach (Manen, 2015). The analysis of Janice's past experiences and moments that shaped her present teaching pedagogy provided a framework for contextualizing Janice's lifeworld and its implications for maker-centered learning. Her pedagogical moments were informed and constructed in the context of her educational background, professional development experiences, and personal life experiences.

A Teacher's Path to Maker-Centered Learning

Janice's personal, educational, and professional development experiences emerged as important factors in shaping her pedagogy and worldview regarding the implementation and application of make-space learning activities. She explained that her knowledge base of maker-centered learning was influenced by her background as well as formal and informal past experiences. The personal background experience was embodied in the care and in precision she learned from her father, which was juxtaposed with the current student mindset. It was evident that "care and precision" functioned as a unit to create a specific meaning that informed her way of thinking about teaching. Understanding the balance between Janice's personal life and her teaching life is extremely important to understanding her mindset and pedagogical presence. Her past accounts provided a windrow to different pedagogical moments she moved to and from in thinking about, building, and dwelling within her lifeworld. She made accommodations for tacking back and forth from her historical experiences to her past professional development experiences, and her present teaching experiences.

Temporality is an important aspect when examining Janice's historical being and experience with maker-centered learning. During interviews, while maintaining a present outlook, she moved from the present to the past to the future to construct meaning. Her current being was intertwined with the navigation of her temporal experiences. Her passion for science, particularly chemistry, was evident throughout the discussions. Her educational experiences, including advanced biology studies, and professional development opportunities deepened her passion for chemistry. In the following quote Janice expresses her uncertainty behind her interest in science, but knew she loved it:

> *Janice: I don't know. I was always interested in science, I mean, I really thought I was going to be a biology major. And um, through the professors, I interacted with in the beginning, I really never intended to be a chemistry major, I still find biology more interesting than chemistry, but um.*

As a point of reference, she started with an experience she had in high school attending a university for advanced studies in biology, which led her to take chemistry in college. She talked about her professional development experience prior to the maker space professional development experience, which showed a connection between those experiences. The same excitement pervaded her language in talking about the maker space experience was contained when she referenced the professional development experience with the nuclear reactor. Her commitment to the notion of care of precision highlighted her ongoing interest in professional development and exploring innovative teaching methods using maker space. The following quotes provided insight into Janice's previous professional development experience:

> *Because being here, being in an independent school you get to do whatever you want to do, you have autonomy so we did a whole unit on nuclear stuff, and the second thing was material, and I went through, I guessed they used to be called the metallurgist but now they are called the material science, engineering group, professional group. And they had a week-long workshop for teachers, I went to Albuquerque, New Mexico, and spent a week playing with all this stuff, we sand-casted jewelry, we did raku pottery with, you used metals in it they have metallic glazes in it. We messed around with glass, we built concrete blocks to see how much weight it could stand; it was all, it was a whole those activities and so much you could bring directly back ...this maker space thing that was like this is really cool.*

Moving from her schooling to professional development to the maker professional development during the interviews shows how her past experiences informed her present state as a teacher. The reflective knowledge Janice presents in relation to the maker space professional development learning experience reinforced her perception that she is “already doing that”. She shared the development of her teaching praxis which she first engaged in as an undergrad and then further developed her praxis in graduate school where she ended up in charge of the chemistry department at a local community college. Janice aligned her career path with teaching as she reflected on the current moment. Relationships are at the center of Janice’s career development. They informed her career decisions and brought her to the tenure chemistry teaching position at the high school. Janice’s interest in the maker movement is found in the statement, “this was the next thing, this maker space thing that was like this is really cool”. Her statements outlined her progression of professional development and why there was interest from her and support from her school to invest in the maker space professional development experience. Furthermore, her willingness to unravel what maker-centered learning appears in the following statement:

> *I think the issue is you have to do enough reading on it to, like this design theory thing, to understand you are doing that, I am already doing that. I just haven't initially attached these words or categories to it, and I think the key for getting making in the teaching curriculum is getting teachers to make that connection.*

Janice’s position as a female chemistry teacher is significant as many women do not pursue the field of chemistry. Not only does she have a bachelor’s degree in chemistry, but she has also obtained her master’s degree in the field and even performed research at a corporate level. She acknowledges her identity as a chemistry teacher. She committed herself to advancement in the school and professional development. Her personal and professional journey highlights the importance of encouraging teachers to explore the connections between teaching, personal histories, education, and maker-centered learning. Such connections could provide valuable insights into teachers’ mindset, pedagogical approaches, and the reasons behind their interest in incorporating the maker-centered learning approach in their teaching.

A Teacher’s Struggles and Breakthroughs in Maker-Centered Learning

Janice’s state of being in the classroom and understanding of the maker-centered learning framework is rooted in her formal and informal learning experiences. This phenomenological connection is encapsulated in the concept of chaotic cohesion whereby Janice feels understanding is being accomplished in what may appear as a chaotic environment at first glance. Janice struggled with the integration of the maker ideas during the initiation process. The following anecdote describes a moment when she translated the abstract ideas she found in the maker-centered framework into a concrete example for another teacher. She explained how maker-centered learning can be applied in another subject area by cooking a French meal, which serves as an example of her creative vision for maker-centered learning.

> *I see the benefit of what I did this summer, the maker things, I am not exactly sure how to do that in chemistry, I see parts of it, and I guess the whole idea of making, it is allowing your brain to expand it to what it means to make, and I think that is a stumbling block for this movement that teachers are doing things that are making, but they don't see them as making, an example was one of our world language teachers said, yeah that isn't applicable to anything in our class, and Celine [pseudonym] said well wait a minute you have them make food. You have them research recipes and they bring in dishes that are from France or whatever, that is making and that kind of concept, that low level idea of making because so much of what is out there when you read about it is like let's go build this and let's design this thing, that is a stumbling block.*

Janice's reflected on her science subject matter as having already been "doing the maker movement". She believed that labs were not "original design", but that there was a "purpose" behind them. The "purpose" supersedes "original design", which did not align with the maker movement's ideals, of student-centered learning through hands-on creation. What is also important from Janice's perspective is that teachers from her school are investigating ways to apply the types of thinking encouraged by the maker movement. Building and designing as well as learning how current classroom practices align with the maker movement could enhance student learning. Janice stated that making in science and labs has intuitive procedures, which embody principles of maker space learning, requiring alignment with the curriculum. She emphasized the importance of having a framework to support student experiential experiences through maker-centered learning.

According to her, maker space provides the opportunity for students to think about real-world connections and it "sets the stage for that next connection" with specific course materials. Her appreciation of the framework as a whole, as a tool that allows students to see how they can apply their learning in the classroom to the context of the world, was evident thinking process. The application of learning in real-world contexts through connections is one of the underlying values found in the maker movement and an ideal that was ingrained in the maker-centered learning framework. Many supporters of maker-centered learning extol the importance of iterations and the value of redoing a problem until fixed. Janice astutely pointed out "if you don't have a framework to look at it, it is harder to figure out where the issue is", which is an important detail to recognize in maker-centered learning. Her pedagogical preferences prioritize repetition and reapplication of knowledge.

Janice tapped into an important message found throughout the maker movement, which is iteration. The power of giving students a chance to learn through mistakes. The iterative design cycle is a big component found in the creation of maker-centered learning (Clapp et al., 2017). It is also assumed in the maker movement that students would have time to iterate their designs and recreate the object with motivation and passion. Janice's initial struggle to implement maker-centered learning strategies in a practical manner was due to the time restraints placed on her teaching. Time in her classroom was clearly defined and restricted, but there was no restrictiveness to her "care" and "precision". Janice presented a workable framework, "teaching on inquiry", but "derided" the time-consuming methods needed for success in this framework. Janice recognized the importance of time in teaching and she felt the pressure to teach her course materials within a defined timeframe. Janice found a balance between curriculum requirements and inquiry-based learning which provides students with the opportunity for exploration. Inquiry-based learning, from her perspective, has potential benefits for student engagement.

Janice wanted to work through specific problems in order to attune students to specific procedures through repetition. Her pedagogical preferences allude to the importance of time while revealing a part of her own being that is enmeshed with the expectation students will utilize their time to the utmost. Her general stance, which is reinforced by the signs in her class and found in their binders from the beginning of the year, focuses on effort in chemistry. Both the sign and quote call the student to embody a 'can do' attitude in and outside of the classroom. Other signs promote similar virtues and mindsets needed to be successful in her classroom and in life. The physical environment and curriculum that Janice has created in her classroom reinforces and reflects a value that hinges on past experiences which have defined an aspect of her being as a teacher and a person who has a deep understanding of chemistry. It created a part-to-whole moment as Janice sought to communicate the parts of chemistry, hard work, and success in life into a comprehensive whole. Janice has in mind to teach chemistry, but also understands what it will take to be successful academically and, in their careers, which also aligns with Janice's understanding of gentle exactness.

Janice expressed disappointment in the lack of clarity regarding measurement units in her course. According to her, this shows a lack of actual application of knowledge that's occurring in chemistry courses. Janice had a clear idea of success in chemistry and expected the students to engage in a similar process. The student could not identify, nor has the life experience and ability to understand her perspective. Getting the students to understand that measurements have significant meanings in chemistry is crucial for a deeper comprehension of chemistry. The understanding of Janice's being as a teacher is supported by her being as a person in her lifeworld. The classroom presented a significant segment of her being.

It was evident that Janice values the maker space learning framework's ability to facilitate learning in real-world contexts, but she acknowledges the challenges of limited time and curriculum requirements. Recognizing the potential of maker space learning, she designed the science curriculum to reflect her concerns for the students to learn the content of her chemistry course to develop their scientific knowledge in high school. The larger curricular choices made in her school stem from the physics first curriculum started by Lederman (2001). This curriculum model argues for teaching physics in the ninth grade and chemistry in the tenth grade. The physics curriculum is designed to build upon the skills and knowledge students acquire in algebra. Furthermore, studying physics with chemistry allows students to understand the physical forces associated with chemistry through their experience with physics. The intentional sequencing aims at providing students with the knowledge base to excel in chemistry. Janine strives to implement a learning model to address student challenges through maker-centered learning activities.

DISCUSSION

Through this single case study, we see moments where Janice recognized maker-centered learning occurring in her classroom as well as the possibilities the maker movement offered in a chemistry classroom. The interviews and observations revealed the construction of students through the lens of specific values including "care" and "precision". The way the teacher interacted with students and the curriculum seemed to be influenced by the maker-centered framework. There was sufficient evidence to suggest that her activities were aligned with three elements of the maker-centered learning framework, which includes looking closely, exploring complexities, and finding opportunities. The framework supposes that students are engaged in the overall learning process through designing a curriculum around the three base principles. It parallels the "being-in-the-world" mindset explored by phenomenologists who are interested in capturing the lived experience (Baldwin, 67 2004). The framework provided a language to explore the complexities of capturing a teacher's lived experienced and allowed a deep close look at Janice's predisposition as she endeavored to understand and integrate the maker-centered learning framework.

The professional development activities Janice engaged including maker-centered learning professional development experience and the student summer enrichment program indicate that she had a disposition for continuous growth and engagement of students through the possibilities of a different approach to teaching. She could simply choose not to engage in an activity that would require more work outside of her direct content area, or outside of school time. The fact that Janice was willing to experiment with elements out of her comfort zone led her to be open to the possibilities offered by the maker movement. One of the more powerful aspects of the maker movement is its use of space to provide students with opportunities to create. Janice's use of maker-centered learning in her classroom seemed to stem from her interpretation of what is necessary for the cognitive growth of the students.

In her case, she had constructed her lifeworld space to reflect an ideology and reality that challenged the demands of the traditional school. The reality of the situation in traditional classrooms is that the space is static. The tables are immovable, as they are in most traditional chemistry classrooms because they each have gas and water lines at each table. The layout of the classroom encourages presentations of new experiments for labs. Therefore, how teaching happens is influenced by the layout and its existing structure. Heidegger calls this "facticity" (Polt, p. 47), the idea that the environment is constructed in a manner that it becomes a part of one's being (Van Manen, 2015). The maker-centered framework assists in creating a rational way to reveal Janice's lifeworld space, as it is underpinned by the idea of sensitivity to design, which also allows for looking closely at Janice in her being-teacher at school. The maker-centered learning framework has disrupted how Janice used to conceptualize teaching and learning. She finds this model offered plenty of opportunities to students for success and she sees the potential opportunities afforded by the maker-centered learning framework if appropriately integrated into her curriculum. Janice's past experiences are influencing present reality, and her future is a combination of the two.

In juxtaposition to many of the pedagogical choices Janice has made is the maker movement. An enduring part of the maker movement is it acknowledges the body as a way to build knowledge through the construction of artifacts. The maker-centered framework focuses on the actualization of student interest and utilizes their motivation to drive learning. The teacher tries to be more of a facilitator as the students look closely, find the opportunity, and explore complexity. Janice aimed to accomplish each one of these framework pieces, but her interpretation seemed to be slightly different. How she achieved that goal was to a certain extent in line with the constructivist and constructionist values. The maker movement has strong ties to constructivism and constructionism (Ackermann, 2001). The focus of constructionism is on the benefit of physical object creation to the learners' conceptual understanding. It introduces an additional dimension to the theory of constructivism whereby the object functions as an "evolving representation of the learner's thinking" (Sheridan et al., 2014, p. 507).

Additional dimensions of interpretation occur as learners negotiate to interpret the artifacts' importance and meaning (Sheridan et al., 2014). The relationship between the mind and body is important to comprehend as the maker movement sees the benefit of their interrelatedness (Rose, 2004). This connectivity allows for the exploration of the importance of the cognitive and physical in competent STEM learning and other subject matter as well. Janice was teaching at her school and has been involved with the development of the curriculum since its inception. And while she implemented elements of a flipped classroom, her approach to teaching has been very teacher-centered. The maker space professional development experiences seemed to have disrupted her perception of how educational environments could be structured. Janice's ingrained thoughts about education can be traced to her personal experience as a student and were influenced by her family. Both revealed the need for hard work, iterative thinking, and the ability to not let failure define the learning experience. The needed scientific knowledge is intertwined with Janice's idea of "precision", which is defined by Janice's ontological being.

Teacher support and mentorship, in addition to professional development, could contribute to a more sustained maker-centered experience for teachers, allowing for a deeper enactment of maker principles alongside the teacher's praxis. Having support to address the challenges of the limited time for integrating maker-centered learning or new approaches, in general, is crucial to teachers' being and the development of self-efficacy (Margot & Kettler, 2019). The potential positive outcomes of maker-centered learning for students, teachers, or schools in Janice's case were not known, making it difficult to argue for full integration alongside current curriculum standards. There is a need for many teachers for support to find ways to integrate making into the classroom efficiently and seamlessly without detracting from their current curricular expectations.

CONCLUSION

The teaching process is filled with overlooked complexities as several factors shape and influence the overall lived experience of the classroom. Janice, a chemistry teacher, is an expert in her subject matter and has a seemingly strong connection with the maker movement. She seemed to understand maker-centered learning as well as the personal and social benefits of creating objects in a maker space. What is profound about this study is gaining an insight into how her new knowledge about the maker movement, as well as the personal experience and new identity she gained through being in a maker space environment for an extended period (Aghaei et al. , 2020). Janice had opportunities to experience the complexities of the maker movement before this study, and time to subsume the complex ideas associated with maker-centered learning.

This study illustrated how Janice interacted with her knowledge of maker-centered learning and how her past experiences influenced and shaped her thinking process, struggles, and growth. There were observed paradoxical aspects of her being evident in her struggle implementing maker-centered learning. The constraints of maker-centered learning lay in its practical application in a modern classroom. Often noted in research is the alignment of maker-centered learning with STEM subjects (Marshall & Harron, 2018). While this alignment seems natural, there are still challenges a STEM teacher must address in executing a maker curriculum. In Janice’s specific case, a school-level adoption of maker-centered learning may have increased the likelihood of substantial change in her teaching practices. Her growth and application of maker-centered pedagogy must be considered in the context of a variety of factors that influence instruction in the classroom.

This study is unique in examining a teacher’s lived experiences and adding to the empirical research which shows how elements of the maker movement can be incorporated into educational spaces. However, it is not easily replicable. The context of the study alone raises questions of generalizability and whether the study contributes significantly to the maker movement literature. Ensuring there is rigor in the study assured validity, but researcher bias and the teacher’s social desirability were difficult to control. Making sure the researcher is bracketing his perceptions and interpretations was important to have an accurate depiction of the teacher’s lived experience with the maker-centered curriculum. Furthermore, the researchers had to be wary of the teacher’s position in her school which might have led her to answer questions less than truthfully. Through rigorous investigation, an accurate picture of what the experience is like for a secondary chemistry teacher experiencing maker-centered learning was captured.

Despite these limitations, the current study contributes to the literature on maker-centered learning and STEM subjects by exploring a teacher’s lived experiences in engaging students to create digital and physical objects beyond the prescribed curriculum. This study provides important findings that can help improve professional development for teachers. Practical constraints in K12 educational environments must be addressed. Teachers' previous knowledge and experience should be incorporated into professional development experiences and used as a starting point to consider maker-centered learning. More research is needed to investigate and record the lived experiences of teachers applying maker-centered learning in their classrooms through different approaches including phenomenological methods. Much has been written about maker-mindset (Culpepper & Gauntlett, 2020), often suggesting that teachers do not currently possess or have not developed a strong enough maker mindset to educate students in the maker movement.

Many elements of a maker mindset already existed within Janice's being and personhood. Instead of focusing on developing teachers' maker mindset, teacher professional development may be more effective by finding practical resources and strategies to support making in classroom environments that are inclusive of teachers' own previous teaching experiences.

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