# Teacher Technology Use: An Interplay of Learning Preference, Teaching Philosophy, and Perception of Technology

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**Abstract.** Teacher technology use is a key element in the successful teaching and learning of STEM (science, technology, engineering, and mathematics) courses. However, even with the increasing availability and number of new technologies and hi-tech learning environments, teachers don't always integrate technology into their teaching practice in a meaningful way. Over the three-year period of this case study, we followed the experiences of two high school teachers working in a depressed urban setting as they began using a newly constructed, innovative, high-tech STEM classroom. Using a grounded theory approach, we analyzed data from a series of semi-structured interviews and classroom observations. Three themes related to the teachers' technology use emerged: personal learning preference, teaching philosophy, and perception of technology. We explore these themes, propose a model that illustrates their relationship, and suggest areas of future research. These findings will be beneficial to anyone seeking to facilitate the meaningful adoption and use of technology by teachers.

**Keywords:** Technology · Teachers · STEM · Secondary education · Teaching philosophy · Teacher learning preferences · Teacher perceptions of technology · Teacher beliefs · Autonomy · Model

## 1 Introduction

Researchers have identified a variety of factors that influence the successful introduction of technology into a teaching setting. These factors include both internal and external factors. External factors include access to technology, sufficient training, technical and administrative support, and the environment and culture of the educational setting, while internal factors include but are not limited to a teacher's self-efficacy, attitude about technology, and openness to change [1–5]. The interaction of these factors is complex, and plays an important role in determining the extent and ways that technologies are used within a setting. Each day, when teachers enter their classrooms, they bring with them a variety of unique experiences and backgrounds, skills, and attitudes about technologies and education [6], and these elements have the potential to impact a teacher's understanding of the benefits and limitations of using technologies in teaching [7]. This paper reports the findings of a three-year case study in which we followed two


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teachers' experiences teaching in an innovative, technology-rich Science, Technology, Engineering and Mathematics (STEM) classroom. Our intent was to identify and understand factors influencing these teachers' decisions on whether and how to use the new technologies in their teaching, as well as explore any subsequent changes in their teaching practice.

Technology use in the classroom has been connected to both increased interest in and engagement in STEM activities, leading to improved STEM teaching and learning; thus, the meaningful adoption of technology by STEM teachers is viewed as essential to student success in STEM [8]. Technology-based lessons are often perceived as more authentic, giving students opportunities to engage in real-world STEM activities and experience using equipment similar to that which real STEM professionals might use [9]. Unfortunately, there is disparity in the availability of and access to technologies needed to teach STEM, as schools in low-income communities do not always have the materials, laboratories, and equipment to teach these subjects effectively [10, 11]. In fact, in a recent Pew Research Center report [12], 56 % of teachers of the lowest income students indicated that a lack of resources among students to access digital technologies is a "major challenge" to incorporating more technology into their teaching.

Additionally, even in schools where technology is readily available, the meaningful adoption of technology by teachers can still be problematic. While having sufficient and up-to-date resources available is important for STEM teaching and learning, access to resources in itself does not guarantee improved student outcomes. Even when technology is used in instruction, it is often not truly employed in transformative or innovative ways, but merely mimics what has always been done in the traditional classroom. In a study involving over 1,000 students, Wang et al. [13] found that the majority of students reported using computers in a school setting primarily for word processing and Internet searches, not for problem solving or creative activities. Although several research studies have identified possible reasons for this ineffective use of technology by teachers (e.g., lack of time, insufficient training, lack of confidence, technical issues, etc.) [3, 13–16], there appears to be no significant improvement in the situation [12].

If teachers are to successfully adopt new technologies, Ertmer and Ottenbreit-Leftwich [17] suggest that they need to change their mindsets to accept the idea that "effective teaching requires effective technology use" (p. 256). However, change, whether in mindset or practice, is not easy. The experiences and beliefs that teachers bring to the classroom have a major impact on instructional practices and willingness to change those practices since new experiences are filtered through teachers' existing beliefs and experiences [6, 17, 18]. One strategy that has proven successful in modifying teachers' beliefs and increasing their confidence and self-efficacy when teaching with technology is to encourage them to make small changes when teaching with technology before attempting major changes. Thus, when innovations are introduced into an educational setting, teachers will require time and support before the innovations can be adopted and implemented to any substantial degree [19].

In a seminal paper, Becker and Ravitz [20], investigated how teachers reported that technology use changed their pedagogy with specific emphasis on the adoption of constructivist practices in technologically rich settings Based on their study of practicing teachers, the researchers found a high correlation between use of the technology and the range of self-reported changes in teaching particularly among secondary science and social studies teachers. They further reported that the longer the teachers used technology in the classroom, the more their pedagogy changed. Time and experiences appear to play important roles in the adoption of new technologies.

The three-year study described in this paper is an attempt to understand how and to what extent change occurs in a particular classroom setting given an influx of innovative technologies for teaching and learning STEM. We were guided by two broad questions: What factors influence the ways and the extent that a teacher uses the newly available technologies when teaching in a high-tech STEM classroom? How does the availability and use of the new technologies change teaching practices?

## 2 Method

In seeking to understand the complex interplay of factors involved in teacher and technology use, we used a qualitative case-study design. This design enabled us to acquire and interpret data from multiple perspectives within the natural setting [21, 22] and to "describe the unit of study in depth and detail, in context and holistically" [21, p. 54]. The variety and detail of data allowed us to create a rich story of the participants and their experiences over the course of the study.

### 2.1 Setting

McCloud High School (pseudonym), the setting for this study, is an underperforming public secondary school located in a U.S. city in a large metropolitan area. According to 2013 data, 97 % of the residents of the city are African American with 41 % of households classified as being below the poverty level. In June 2014, the unemployment rate in the city was 13 %.

McCloud High School has been in existence for approximately 17 years. During the 3 years of the study, the school averaged 110 students all of whom were African American and between the ages of 13 and 19 years. The school employs three full-time STEM teachers and offers a range of STEM courses, requiring students to successfully complete 3 years of mathematics and 3 years of science in order to graduate. In 2012, the school began to introduce courses from a pre-engineering program, Project Lead the Way (PLTW), into the curriculum.

In 2011, the school received a major gift for construction of a classroom containing a variety of innovative technologies, including 3D printer, video wall, robotics kits, humanoid robot, graphing calculators, iPads, and high-definition video conferencing. This STEM classroom was designed with teacher and student input, along with guidance from the director of a nearby university's STEM Center, to be a flexible, high-tech learning space that fosters collaboration and creativity [23]. The classroom and its technologies represented an educational innovation with the potential to catalyze major changes in teaching practice. Prior to construction of the STEM classroom, the school had access to two outdated computer labs that often were not fully operational. Most of the school's traditional classrooms have a projector and teacher laptop, and a few of the classrooms have been equipped with SMART boards.

The study began with the initial planning for the STEM classroom in late spring of 2011 and ended in the summer of 2014. Both of us who served as researchers for this study are researchers affiliated with the university's STEM Center. We conducted all data gathering and analysis. In our role as researchers, we attended meetings and other events associated with the school and the new classroom (e.g., visits to high-tech schools, STEM classroom open house, monthly STEM staff meetings) in order to better understand the environment. We also supported logistical aspects of the classroom's implementation, often helping to coordinate events between the high school and the university or other external groups, and so had regular opportunities to interact with the participants.

## 2.2 Participants

We chose our two participants purposefully in order to obtain the most meaningful, relevant, and detailed information possible. Both Ms. Beech and Mr. Aspen (pseudonyms) were full-time STEM teachers employed at McCloud throughout the entire time of the study and have been closely involved with the STEM classroom from its early design through its final implementation. Additionally, both teachers attended project-planning meetings for the new classroom, providing valuable input to the design team on the room's layout, furniture, and technology. They also made several visits to high-tech schools and participated in technology-focused professional development. They began teaching in the room as soon as its construction was complete and continued to teach in the room throughout the study, giving feedback on their experience to the project partners at regular monthly meetings. Their continuous, close involvement with almost all aspects of the STEM classroom made them ideal sources of information regarding its impact on teaching practice at the school.

Ms. Beech is an African-American female in her sixties. At the time the research study was initiated, she had been teaching science and math at McCloud High School for 4 years. She had previously taught science for 2 years immediately after graduating from college in the late 1960s, but then entered the business world as an IT professional. She reported having a very satisfying career, saying "I really, really enjoyed IT in my day. There was such a joy in designing and building systems and making them work." She retired from this work after 37 years, during which time she filled many roles from programmer to analyst to manager and also earned a master's degree in business administration (MBA). After retirement from her IT position, she returned to school to earn a master's degree in teaching science. She continues to increase her knowledge and skills as a teacher by participating in a local university's professional development program designed to improve science teaching and student learning. During the time of this study, she taught a variety of courses including biology, chemistry, physics, pre-calculus and anatomy. She also participated in summer workshops to prepare her to teach an introductory PLTW course. Ms. Beech believes it is her responsibility to share with her students what she has learned: "I took all those courses … and so it would be a sin not to give them everything I got." Her teaching style involves a lot of interaction with the students and checking individual students' understanding of concepts: "[I want] to know what each individual is doing as opposed to one or two people…I talk to them all the time. I'm a living and breathing example of 'this is what you do in life.'" She believes that in addition to helping students get "a better, deeper understanding of the concepts," she has an important responsibility to help students learn to use what they already know, to think creatively, and to acquire "habits that will help them get through" life.

Mr. Aspen is a Caucasian male in his twenties. When the research study began, Mr. Aspen was in his first year of teaching after having completed a bachelor's degree in biology and a master's of arts degree in teaching science (MAT). He became familiar with McCloud High School through his time as a student teacher there. His teaching responsibilities included algebra, geometry, general science, and introduction to engineering. In addition, he assisted with the school's robotics team and a university-sponsored game design club. Mr. Aspen is very comfortable with a range of technologies. As he approached his fourth year teaching, he decided to enroll in an online master's program in computer science because of his interest in technology and the flexibility such a program offers. Mr. Aspen described mastering more "problem solving skills" as one of the main goals he has for his students. He added: "[I want them] to be able to do a lot of different things pretty well or come up with different answers rather than be able to do [one thing] like integrals or quotients really well."

### 2.3 Data Collection and Analysis

Primary data sources included a series of semi-structured interviews and direct observations in both the traditional and STEM classrooms. Interviewing began during the design of the room so as to get an understanding of each teacher's background and their experience teaching in their regular classroom. Over the course of the study, we conducted three hour-long interviews with each participant as well as a final 'participant check' interview. The initial interview protocol included questions on the participants' education and teaching history, use of technology, and classroom environment. Subsequent interviews were more open, allowing for the flexibility to pursue emerging themes and issues.

Observations began early in the project, again to get a sense of the teachers' experiences in the context of their regular classroom. Later, after completion of the classroom, participants were observed in both the STEM classroom and a regular classroom. When possible, we observed the same class taught in both the traditional and the STEM classrooms. Together, we observed each teacher numerous times, giving us direct experience with the school setting plus the opportunity to notice things that might otherwise seem routine (and therefore go unmentioned) by the participants [21].

As with any qualitative study, data analysis began and overlapped with data collection. We used NVivo software to facilitate the analysis, but also coded much of the data manually. Field notes were taken by hand. Interviews were audio recorded, then transcribed by one of us or by a graduate student assistant. Although we always interviewed and observed our participants together, we coded the transcribed data independently, using a constant comparative process as described by Corbin and Strauss [24]. We began with open coding–reading through transcripts and looking for meaningful units of data. These units of data were then grouped into categories. The development of these categories–or themes–was guided by our research questions as well as by patterns that emerged. As categories arose, they were constantly refined as more data was collected and analyzed. Then, for each category, we developed and defined its properties and dimensions, allowing us to "differentiate a category from other categories and give it precision" [25, p. 117]. Properties are particular attributes of a category; dimensions delineate a continuum along which a property can be located. For example, participants discussed aspects of their *personal learning preference* (category), which had an attribute of control of learning or *locus of control* (property). However, this property can vary from completely self-directed or *internal* to completely other-directed or *external*. Then, we located each participant along each dimension's continuum, allowing us to discern important characteristics about the participants and to make comparisons between them. This grounded theory approach to analysis kept us focused on the data, helping us to form well-developed categories while keeping a lookout for newly emerging ideas.

To increase the credibility of our findings, we used several types of triangulation–multiple methods, multiple sources of data, and multiple investigators [26]. Interview and observational data supported and were used to check each other. Additionally, member checking helped to ensure credibility. Each interview was an opportunity to clarify and expand upon the developing themes; and during the final interview, we asked each participant specifically to comment on our interpretation of their previous interview responses and their classroom activities. Our aim was to build in triangulation throughout the study, weaving together data collection, analysis, and verification [27].

## 3 Results

We found that the teachers' use of technology reflected an interweaving of their beliefs about teaching and technology with their personal learning preferences and accumulated life experiences. In this section, we present three categories (or themes) that emerged from the data analysis and represent aspects of this intricate relationship between teacher and technology use. For each theme, we briefly define it and then discuss it in terms of its framework of properties and dimensions (Table 1), using participants' quotes as further illustration.

### 3.1 Personal Learning Preference

One theme that emerged was personal learning preference. We defined personal learning preference as the teacher's self-described way that she or he learns best, both in and out of formal settings. Outside formal settings, learning may be pursued because of personal interest or belief that what is learned might be of use personally or professionally. The learner determines the pace and setting as well as what and how learning occurs. In contrast, formal settings involve planned learning in which someone other than the learner structures the learning goals, environment, content and process. Each teacher gave various examples of how they learned in both types of settings, with both teachers speaking of learning independently. For example, Mr. Aspen described how he would learn to use new software: "I would just look online until I found something that would be a nice tutorial." Ms. Beech was similarly independent: "I spread out at my kitchen table, I take a book, and I go at it." The teachers also emphasized the personal nature of learning and the need to "own" one's learning. Ms. Beech explained, "In my mind, it seems to me that learning is a personal thing. People can guide you as best they can but individually you have to make it your own." Mr. Aspen also felt that individuals needed to personalize their own learning: "I think it's really important that they learn what works for them." Both teachers saw the control of and responsibility for learning residing internally, within the learner, allowing individuals to make choices about when and how they learned.

However, despite agreeing on the importance of learner responsibility and independence, there were some basic differences in their personal methods for learning. Mr. Aspen described a technology-oriented and multi-method process:

> My hierarchy is written tutorial, picture-based tutorial, video tutorial. So I would probably start working my way down until I found what I wanted. I've never been able to sit through a lecture and take notes and then understand what's going on by those notes. I have to do multiple things.

In contrast, Ms. Beech described her preference for traditional, written materials and a more focused approach: "I used to love reading IBM manuals, God in heaven, I longed for it, I did, because you could read it and you could understand." She also shared her dislike of online tutorials and "help" options with "snippets of this and snippets of that," describing them as "appalling." For both teachers, the ability to choose how they organized their learning (internal locus of control) was important, but the actual organization varied significantly, with one being more structured and the other being more freeform.

There were also differences in the physical learning environment preferred by each teacher. Ms. Beech described needing quiet, more controlled surroundings: "Sometimes things will pop off the page, and so you need to stop and ponder it. I don't learn in chaos." In contrast, Mr. Aspen described a more chaotic learning environment: "I do all my work sitting on the couch at the coffee table with a dog running between my legs and [the] TV on." So, again, the teachers acknowledged the importance of having internal control over their learning environment, choosing the atmosphere that suited them best. One teacher preferred a very calm and structured atmosphere, while the other was comfortable studying in a more disordered setting.

**Table 1.** Categories (factors) and their properties and dimensions.

| Category | Property | Dimension |
|---|---|---|
| Personal learning preference | Locus of control | External - Internal |
| | Locus of responsibility | External - Internal |
| | Organization | Freeform - Structured |
| | Atmosphere | Calm - Chaotic |
| Teaching philosophy | Role of teacher | Lecturer - Facilitator |
| | Role of student | Passive - Active |
| Perception of technology | Personal value | Practical - Entertaining |
| | Educational value | Narrowing - Expanding |
| | Impact on teaching | Restricting - Enhancing |

Finally, we noted that the teachers' learning preferences also showed up in their opinions of professional training. Neither teacher is a fan of traditional professional development, particularly for learning about technologies. Mr. Aspen preferred to 'tinker' rather than participate in formal training on how to use technology tools. Ms. Beech described her frustration with the rapid pace of professional development on technologies:

> You've got some of the worst training, in my opinion, because people who run the seminar will say 'do this, do this, do this' and you want to say 'for real?' And then you're supposed to be expert in that.

The traditional professional development format, with its tendency to have a more external locus of control, didn't meet their desire to be in control of their own learning (i.e., to choose when and how to learn). They had a need for autonomy and to learn in an environment with which they were comfortable.

## 3.2 Teaching Philosophy

A second theme concerned each teacher's personal teaching philosophy. We defined this as the teacher's personal beliefs about how teaching and learning occur combined with examples of how the teacher puts these beliefs into practice when teaching. Both teachers spoke at length about what should happen in the classroom and what they did to optimize teaching and learning. Both valued direct interaction between teacher and students, usually in the form of meaningful discussion or dialogue surrounding questions or problems. Ms. Beech acknowledged that she did a lot of talking when teaching, but not as lecture: "My teaching style is probably to talk, but talk with the students. I like interacting with them, I just do. You've got to stop, pause, and discuss." Mr. Aspen saw interaction as an opportunity for questions: "I want some dialogue with students along the way, allowing students to ask more questions."

Often, the purpose of this dialogue was to assess a student's level of understanding and to elicit a student's thinking processes, making them visible to both teacher and student. Ms. Beech's approach to teaching very much emphasized this:

> You've got to talk about what got written so that the teacher can be assured that the students are getting where they need to be. I need to know what they know. We could be going on and on, and I'm thinking that things have been communicated and are well understood. Then you start talking to 'em and you realize that that whole boat was missed! So those are opportunities that you get to find out where they are. For me, it takes interaction because the room is full and you got people at different levels of interest and different levels of preparedness.

Although more teacher-centered in appearance, her role in the class discussion was very purposeful, and she did not see herself as a lecturer.

When observing teaching sessions, whether in the STEM classroom or the traditional classroom, we saw Ms. Beech continually using questioning to engage with students (teacher asking students, students asking teacher) with lots of give and take occurring between the teacher and the students. Through her interactive style, she made sure all students were included and accountable for what was being taught. Similarly, Mr. Aspen stated: "Asking more questions to figure out where we need to go is a lot of how I am." Both teachers felt that students should be actively engaged in the classroom activities and in their learning.

Additionally, each teacher saw their role as one of facilitator or guide, providing critical structure and direction to the students' learning experiences. Ms. Beech referred to one of her classes as "more of a seminar type thing," with her guiding class discussion to elicit student thinking and assess student understanding:

> We do a lot of conversing, and I really like the physics class because we can sit and talk about things and they [the students] really are good at sharing their thoughts and questioning what someone else has done. They're freer to just say, "um, I don't think you're right there," and then talk about it. I really like that kind of thing. They will even do that among themselves and do it politely, and that's really a good thing.

Utilizing a slightly different type of guidance with his students, Mr. Aspen specifically referred to himself as a facilitator and coach:

> I want to be engaged with them, have them be the primary speakers and me be a facilitator of education rather than an expert of education. What's been helping me through a lot of things and helping a lot of the students through is providing set and clear, established expectations for what they need to do. Today I wrote what you need to do to get every bit of points right on that board (points to board in front of classroom) at the beginning of class, showing them, okay, this is what we are going to be doing, more of a learning coach than a knowledge giver.

For both teachers, meaningful classroom interaction was the key to successful teaching and learning.

Interestingly, Mr. Aspen's philosophy evolved somewhat during the period of the study, changing from unsure and idealistic to more confident and realistic. During our final interview, he described this shift in his teaching:

> I am teaching differently than I used to because it used to be a very binary system. I was really way too far on the progressive side, or I was way too far on the traditional side. I tried to do something, and if it didn't work out like I wanted it to, I would fall back to this 'lecture and do problems from a worksheet' sort of thing.

As an early-career teacher, Mr. Aspen was still finding the best way to meld the ideals of his teaching philosophy with the realities of the classroom.

Teaching philosophies tend to evolve with experience and over time. Dexter et al. [7] attributed the evolution of teaching philosophy to a teacher's experiences in the classroom, and reflection on those experiences combined with the professional culture of the school. During the 3 years of the study, we saw changes in the way Mr. Aspen taught, which he attributed to moving from being a novice teacher to a more experienced teacher and to reflecting on the outcomes as he tried different teaching approaches. Early in his first year of teaching, Mr. Aspen stressed: "I am very much not a traditional style teacher. I have found it a lot easier to put the work on students rather than me." However, following his third year of teaching, he admitted that his philosophy had changed:

> I am no longer under the assumption that I can change education for kids overnight… I've actually gotten more traditional. I wouldn't say that I am a traditional teacher, though. I think I lecture more and introduce concepts more at the beginning of class than I used to because I found that kids are more familiar with that [approach] and receptive to it and so I try to pick out

specific concepts that, if I know they're going to run into this problem within the first five to ten minutes of them working with something, then I try to address it up front.

Thus, as Mr. Aspen gained teaching experience, he began to think differently about what works best in the classroom and to make small modifications to his teaching practice in both classrooms.

## 3.3 Perception of Technology

A third theme concerned each teacher's perception of technology. We defined this as the way a teacher views and uses technology, both personally and professionally. Both teachers viewed technology as a tool, something that could be potentially useful in and out of the classroom. Each teacher spoke of the many practical advantages to using technology. Mr. Aspen believed that knowing how to use technology is essential in today's world. He considered himself tech-savvy, regularly using the Internet and technology gadgets in his daily life, and is a self-proclaimed 'geek.' Ms. Beech also valued technology, but emphasized its more practical uses:

I really do appreciate cell phones because there are a lot of needs in an emergency. I used to have to write things by hand, and when I started [working] it was punch cards. Then it evolved… so technology, in that sense, is a good thing, and it really has helped the countries of the world. I think you get so much productivity with technology.

For Ms. Beech, technology's value resided more in its impact on safety and efficiency and less in its potential for entertainment and education.

In addition to personal entertainment, Mr. Aspen described how technology helped him to be more productive, adaptable, and flexible in his classroom:

I was going to have an end of year survey for my students and get feedback from them, and I was actually able to just say, 'Okay, everyone go get an iPad.' I was able to make a Google form in the time that it took them to go get that and come back, and I just did it that way. It's nice to have that adaptability. A lot about it [technology] is the flexibility that you have. If I need some kids to just swing over and start working on something online, or on a computer, or a quick self-check quiz, or a Kahn Academy lesson or something like that, it's really nice to have the flexibility to do that.

Technology expanded his options in the classroom and enhanced his teaching.

While Mr. Aspen embraced the use of technology in teaching, Ms. Beech questioned its role in teaching and stressed that she will not use it "just for the sake of using it." She worried that technology has been too widely and too quickly accepted:

I get the sense that there's a lot of looking outside of current resources to access a lot of stuff that apparently is effective. I think technology is a good thing. I have not bought into technology being a replacement for [the] teacher; I just haven't bought into that it replaces interaction with students. I really don't want to imply that that's a general perspective on technology, but with the constant hype about using technology, I think that you're left with the impression that if you're not using technology, then there's definitely something wrong with you. I think that if the teachers work at it, and if the technology can facilitate more learning in some way, then it'll be a good thing.

While Ms. Beech questioned the use of technology in teaching, she was aware that, with effort, it could be used effectively. The main drawback in learning to use technology effectively in the classroom, according to Ms. Beech, was the time it required to find good resources that could be integrated in a way that promoted student learning. She viewed technology as limiting student learning:

> What happens, I think, is that when you rely too much on technology, kids will learn a pattern and they will not understand the pattern; they cannot transfer it. So what I need to know is how much technology do we get that actually focuses on the ability to transfer?

While she perceived technology as potentially narrowing students' learning experiences, she also sensed that with time and effort teachers could make the difference and ensure that technology facilitated learning.

## 4 Discussion

The results of this study highlight the impact that teachers' experiences, beliefs, and perceptions have on their use of technology. Both teachers in this study were presented with a new and very unusual teaching environment: a high-tech STEM classroom designed for flexibility. In addition to this new room, the teachers were provided with a technology support specialist, customized professional development, and the support of the school's administration, as a lack of these items has been identified as a major factor influencing teachers' adoption of technology [3, 14, 28]. Both teachers made use of this environment, bringing their students into the STEM classroom on a regular basis and using its new technologies. Over the course of 3 years, as the teachers became familiar with the innovations, we noticed small changes in how they used technology in their classroom teaching. For example, Ms. Beech had students teach the class about using graphing calculators, incorporating some peer instruction into her normally teacher-centered classroom. Becker and Ravitz [20] found that a major change reported by teachers when using technology was willingness to "let go" and allow students to assist in teaching about technologies with which they were not familiar. Ms. Beech may have been taking a first step in that direction. Meanwhile Mr. Aspen, initially allowing his students to explore with technology as much as possible, incorporated more direct instruction into his class by the end of the study, stating that technology needed to serve him and not the other way around. This change may be a combination of his experience with the STEM classroom's technologies and his gain in years of teaching experience, moving from novice teacher to expert.

Nevertheless, despite these modest changes, we did not observe any significant change in the way technology was used by either teacher or in the overall way that they taught. Each remained true to their own core beliefs and viewpoints—beliefs and viewpoints that lie at the heart of their teaching philosophies and their perceptions of technology, and that appeared to be largely shaped by their life experience and personal learning experiences. Research by Ertmer et al. [29] supports this alignment between personal beliefs and technology integration. On the other hand, our findings contrast with those reported by Becker and Ravitz [20] who found a strong relationship between technology use and pedagogical change among secondary science teachers; however while these researchers described a causal relationship between technology use and pedagogical change, they questioned whether this underlying relationship is limited to teachers who already were inclined to teach in a constructivist manner.

Several other researchers have studied the effect that teachers' beliefs have on their teaching behaviors and their adoption of innovations [4, 9, 30, 31]. For example, in a study of factors influencing adoption of inquiry learning curriculum in science, Roehrig et al. [18] reported that teachers' beliefs combined with school support played an important role in how a new science curriculum was implemented. Furthermore, teachers' practices and beliefs are formed based on various aspects of the teacher's background, including professional background, content and pedagogical knowledge, knowledge of technology, beliefs about teaching, classroom activities, classroom and school level environments, the teacher's technology self-efficacy, and professional activities [5, 6, 32]. Our findings are consistent with results of these studies and contribute to the international literature on factors influencing teachers' use of technologies [1, 3, 6, 33].

The three themes that emerged from the data create an interrelated set of factors that directly and indirectly influenced the teachers' use of technologies (Fig. 1). The first theme, the teachers' personal learning preferences, directly influenced both teaching philosophy and perception of technology and thus indirectly guided their use of technologies in teaching. As self-described independent learners, the teachers encouraged their students to be the same, to ask and pursue their own questions and take responsibility for their own learning. Often, as in the case of Mr. Aspen, this independence showed up in the differentiation that was built into the lessons, allowing students to work at their own pace and on their own projects using the technology of their choosing when possible. Ms. Beech expected her students to go beyond what was covered in class and to work independently to learn more on their own time. Both teachers held the strong belief that students have to "make learning their own." No matter what happens in the classroom, the responsibility and control of learning resides within each student. This strong internal locus of control and responsibility made up a large part of both teachers' personal learning preferences, and in turn, formed a significant part of their teaching philosophy and impacted their perception of technology. By the end of the study, it was evident that both teachers teach with technology according to their own teaching philosophy and perception of technology, which were strongly influenced by the way they preferred to learn.

The second theme, teaching philosophy, is strongly tied to what teachers believe to be best in education, including their beliefs about effective pedagogies. We observed elements of each teacher's teaching philosophy directly impacting their use of technology in both the traditional and STEM classrooms. For example, each teacher believed in the importance of verbally interacting with students–not lecturing them, but talking *with* them. Neither teacher saw him or herself as a traditional lecturer; talking was used very purposefully to elicit student thinking and to gauge student understanding. Mr. Aspen regularly took advantage of the numerous projection options in the new STEM classroom to display individual student work on computers and engage students in discussion about that work. Even Ms. Beech, who considered herself more of a knowledge giver than facilitator, expected her students to take an active role in their learning. When she began using PowerPoint slides in classes, she used them as a basis for class discussion. Both teachers encouraged students to ask questions, listen carefully, and thoughtfully discuss the material. They valued student-student interaction as well as student-teacher interaction, and both teachers expected their students to become critical thinkers and independent learners. Even though the teaching environment changed and technologies were introduced into it, the philosophy of teaching still guided teaching practice and was a primary influence on their use of technologies. Stephen [35] found a similar relationship between teaching philosophy and how and when teacher-designed lessons incorporated technology.

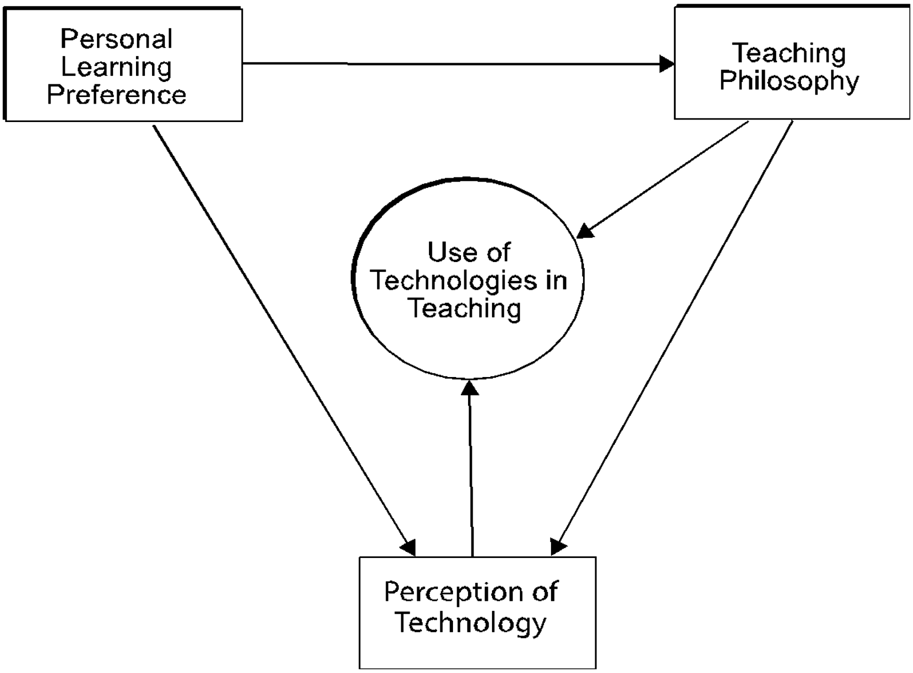


**Fig. 1.** Relationships among factors influencing teachers' use of technologies.

Since the new STEM classroom was equipped with a variety of new technologies, it is not surprising that the teachers' perception of technology emerged as a prominent theme in our analysis, directly influencing the classroom use of technologies and, at the same time, being directly influenced by both the teacher's personal learning preference and teaching philosophy. Other researchers have identified the influence of teachers' beliefs about and perceptions of technology on their decisions on when and how to use technology in teaching [33–36]. For instance, Stephen [35] found that a teacher's perceptions of computers and of students' competence with computers directly influenced the type and amount of computer-supported activities in a classroom. Ertmer's [33] review of studies that examine how teachers' beliefs about pedagogy affect technology use highlighted the complexity of this relationship. Although beliefs are difficult to change, she suggested that strategies involving personal experiences, vicarious experiences, and socio-cultural influences may be successful. Finally, Teo [36] proposed a model of teacher technology use based on a combination of constructs from three previous models. Several constructs involved perceptions about technology: perceived usefulness, perceived ease of use, and perceived behavioural control. Teo found that if teachers perceived that technologies were useful and would increase their productivity, they were more likely to use them in their classroom. It is clear that teachers' beliefs drive their practice.

In addition to beliefs, we saw that teachers' background experiences played a role in their perception of technology. In our study, both teachers saw value in technology (e.g., increased productivity, efficiency, flexibility), but Mr. Aspen's all-out embracing of technology–even the playful aspects–contrasted strongly with Ms. Beech's more skeptical and practical view. This wide difference in viewpoint is in line with their very different background experiences. Ms. Beech's years of working "behind the scenes" with large computer systems gave her a very particular lens through which to view education's current emphasis on bringing new technologies into the classroom. She believed that "technology dictates behavior." She explained, "If you use technology, you're going to use the technology the way that a designer's built it." At one point, she referred to today's technologies as "toys." On the other hand, Mr. Aspen comes to technology with more of a consumer viewpoint, perhaps better able to appreciate the entertainment aspects of technology. Ertmer [33] describes how teachers' early experiences stay with them and affect their perception of later events, often acting like a filter through which new ideas must pass. Jones and Dexter [38] found that formal professional development activities organized at an administrative level often ignore the experiences and knowledge of teachers and stifle their creativity in using technology in teaching. Therefore, for adoption of technology to be successful, it must take into account teachers' previous experiences.

During the course of our study, several other interesting factors emerged. Even though the teachers were expected to utilize the technologies in the new classroom, the school administration gave them the freedom to decide *how* they would use the technologies and how quickly they would adopt each technology. The teachers were given some control and given the chance to assimilate the innovations into their own teaching practices according to their own teaching philosophy, learning preferences, and perceptions of technology. Furthermore, professional development occurred in progressive stages, with the teachers deciding on the format, when it would occur, and what technologies it would address. It has been suggested that this type of autonomy not only plays a critical role in motivation and creativity but is actually a basic human need [37]. Our participants certainly valued being in control of both their teaching and their learning.

In addition, Jones and Dexter [38] identified the role of informal collaboration among teachers as a factor in increasing technology use in the classroom. In this respect, our two teachers differed significantly. On the one hand, Ms. Beech preferred to work independently:

> Mr. Cedar [pseudonym] and Mr. Aspen, they do a lot of teaming up in there [STEM classroom]. That ain't for me. I interact with my students, so if there's another class in there, you know, it's like being in a one-room schoolhouse. It's just not my mode. I've been invited to team with them, and I have to say, I don't do one-room schoolhouses. My sister went to a one-room

> schoolhouse, and she always paid attention so she skipped [a grade]; but she always felt as if she missed something. It is also a sign of a past time that I won't indulge in necessarily, and so I would avoid that type of collaboration at all costs.

On the other hand, Mr. Aspen sought out opportunities to collaborate with colleagues in the STEM classroom. On several occasions, his class shared the space and resources simultaneously with another class:

> Mr. Cedar and I have been having our seventh hour class in the STEM classroom together. He's got six [students] and I've got twelve, and it works pretty well. Again, organized chaos. It really helps having the different learning spaces. He occupies two of them, and I occupy four of them and that's it. He'll answer some of my students' questions and I answer some of his students' questions. We teach each other's students all the time.

Mr. Aspen enjoyed the experience of co-teaching in the STEM classroom, and this is not surprising, since he had described his own personal learning environment as somewhat chaotic. Similarly, Ms. Beech's personal learning preference for a more controlled, quiet environment leads her to prefer teaching independently.

Finally,, with respect to the perception of technology, we noted a generational difference in the participants. Mr. Aspen showed much more confidence towards and willingness to embrace technology than Ms. Beech. Mr. Aspen was quick to try out new technologies in his classroom, while Ms. Beech seemed more skeptical. Although research conducted by Wang et al. [13] did not find this difference, this observation is supported by a recent Pew survey [12] that saw differences in teachers' responses to technology based on age group. According to the survey, teachers under the age of 35 were more likely than teachers age 55 and older to say they were "very confident" about using new digital technologies (64 % vs. 44 %). However, although this same survey reported that the oldest teachers (age 55 and older) were more than twice as likely as their colleagues under age 35 to say their students know more than they do about using the newest digital tools (59 % vs. 23 %), our participants both believed that their students were much more tech-savvy than they were.

## 5 Implications

The results of this study have implications for those seeking to maximize teachers' adoption of technologies into the learning environment. First, teachers' beliefs—formed and solidified over years of life experience—direct much of what happens in the classroom. These beliefs are deeply tied to teaching philosophy and perception of technology, making them a core factor in classroom technology adoption. In fact, Ertmer [33] suggested that in order to increase teachers' uses of technology to increase student learning, we must "consider how teachers' current classroom practices are rooted in, and mediated by existing pedagogical beliefs." Professional development activities that recognize and acknowledge the role such beliefs play by including strategies that help teachers expand their existing teaching philosophy to include technology use and that help teachers extend their perception of technology are more likely to be successful than activities that do not. For example, Ertmer [33] offered three strategies for teacher professional development that may help to change teacher beliefs. First, utilize personal experience. Give teachers opportunities to implement small changes and to be successful. Then, beliefs will begin to change. Second, provide vicarious experiences. Confidence in using technology will increase when watching others model this effectively. Third, encourage positive and supportive socio-cultural influences (e.g., learning communities and peer expectations of technology use). The influence of social networks and the school environment can be critical to how teachers view technology. Finally, it is important to realize that modifying beliefs and perceptions take time, and thus, so do change and the adoption of innovations.

In addition to beliefs, teacher autonomy may play an important role in the successful adoption of innovations. Both teachers in this study valued being in control of their own learning and having the opportunity to determine what they would learn, when they would learn it, and at what rate. It seems that their personal learning preferences along with a strong internal sense of "what is best" for teaching and learning influenced their classroom practices. Therefore, strategies that acknowledge and work with teachers' different learning preferences, combined with allowing teachers to decide their best learning path, may promote the best outcomes during any type of change process. Successful adoption of technology requires attention to teacher differences and plenty of options for teacher choice.

## 6 Limitations and Future Research

Generalizing the results of any case study should always be undertaken with care. Even so, our results are consistent with several other studies that have focused on teachers' adoption of technology and teachers' reaction to change [6, 17, 28, 30, 33, 40]. Furthermore, the case study design itself provides enough detail and rich description to allow other researchers to decide upon its transferability. Some of this detail comes from our participants. While our study focused on only two teachers, they were very different in almost every respect: demographics, personal and professional experience, and in most personal beliefs about technology and pedagogy. This maximum participant variability provided us with rich data and allowed us to capture a wide range of ideas and themes while reducing the chance of missing an important concept. In fact, this wide range of ideas renders this study very useful, as some of the details from this specific context will be found in most other educational environments. As Merriam [26, p. 225] states, "the general lies in the particular."

Since we studied a complex, active environment for over 3 years, it's not surprising that a variety of outside events impacted what we observed in these classrooms. Over the course of the study, many changes took place in the school and in the district. For example, a new director was hired early in the study and initiated the PLTW program as well as other initiatives. New after-school programs were implemented, many of them STEM-related. Mr. Aspen gained 2 years of valuable teaching experience, significant for a beginning teacher and most likely accounting for the evolution of his teaching practices over the course of the study. A longitudinal project is subject to these issues, but since the process of change can be lengthy, it was critical for us to spend enough time with our participants.

One area of future research should address the role autonomy plays in the adoption of technology and the modification of teaching practices. Some authors have discussed autonomy in relation to school change, teacher job satisfaction, and professionalism [41, 42]. Common [40, p. 205], for example, explained that teachers often have an image of themselves as having "characteristics of power, action, autonomy, and stability" while many school reformers hold a view of teachers that is quite different: "powerless, passive, uniform, and changeable." The disconnect inherent in these two conflicting images may be a key element in the failure of many educational reform efforts. More specifically, Pearson and Moomaw [42] found that curriculum autonomy was inversely related to on-the-job stress, and general teaching autonomy was positively linked to empowerment and professionalism. Ernest [39] discussed the role of autonomy and reflection in changing teacher beliefs and enacting a new mathematics curriculum. However, none of these authors examined the role of teacher autonomy in the change process specifically when the change involved technology. It is clear that additional research focusing on the impact of teacher autonomy in the adoption of technology-based innovations and on the subsequent modification of teaching practices is still needed.

A second future research area involves our proposed model of factors that impact teachers' technology use (Fig. 1) and its transferability to other educational environments. This model emerged from one particular setting, but educational environments vary greatly, both physically (e.g., classroom space and design, available resources such as books and computers, outdoor facilities, etc.) and socially (e.g., student culture and background, teacher colleagues, support and expectations of administrators and parents, etc.). Each different context has the potential to impact teacher practice in a unique way. In fact, Ernest [39] included social context in his model of teacher beliefs about teaching mathematics, stating that "the social context of the teaching situation, particularly the constraints and opportunities it provides" was a key element on which the practice of teaching mathematics depends. Therefore, it is important to study a model of teachers' use of technology in a variety of school settings in order to determine if the factors and their interactions appear in the same way. Examining this model in different contexts will lead to a better understanding of how and why teachers use technology and allow administrators to better support and guide teachers throughout the adoption process.

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