Using a Participatory Design Approach to Create and Sustain an Innovative Technology-rich STEM Classroom
One School's Story

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Keywords: Participatory Design, Co-design, Technology-rich STEM Classroom, Learning Environment, Innovation, Stakeholders.

Abstract: This paper describes the design and implementation of a technology-rich STEM classroom in a secondary school associated with a comprehensive U.S. Midwestern university. Built to address a waning interest in STEM and STEM careers, this classroom offers multiple technologies and an engaging, flexible physical space that together create an innovative learning environment. A participatory design approach was utilized in order to maximize the use and sustainability of the classroom. Students, teachers, and administrators from the secondary school worked in collaboration with university faculty and staff and with Herman Miller®, an international design company that conducts learning-space research. In addition to the design process, this paper outlines successes and challenges encountered in implementation, as well as strategies used in addressing the challenges, providing guidance for other educational organizations seeking to infuse advanced technologies into classroom design and instruction.

1 INTRODUCTION

In February 2012, McCoy High School (pseudonym), a public high school in the U.S. Midwest, opened a high-technology classroom designed to be an innovative environment for teaching and learning in science, technology, engineering, and mathematics (STEM). This STEM classroom was created in response to a call for an increasing focus on STEM education in U.S. schools, as articulated in several high-profile national reports (National Research Council, 2011; National Science Board, 2010; PCAST, 2010). These reports emphasize that STEM education is the foundation for many of the high-growth sectors of the economy. In response to these reports and to a growing number of federal and state initiatives, local school administrators and teachers are looking for practical solutions to enhance the quality of STEM instruction, and this issue is not limited to the U.S. (Berguard et al., 2012; Joyce and Dzoga, 2011; Marginson et al., 2013).

Many schools are turning to computing technologies as a means to improve STEM education because there is a growing consensus that students should be exposed to the advanced technologies and tools used by practicing scientists and engineers (Cohen and Patterson, 2012). McCoy's STEM classroom provides students who are living in an urban, high-poverty community with access to some of the latest technologies and tools of STEM as part of their learning experience, with the long-term goal of raising student achievement and inspiring students to pursue STEM university degrees and careers. The classroom incorporates design elements that reflect recent understandings of effective ways to promote and support STEM learning, and includes features that the STEM teachers and students feel are important for facilitating learning.

In this paper, we describe the design, development, and implementation of McCoy High School's STEM classroom. We discuss some of the challenges encountered during the process, including approaches taken to meet these challenges, and finally highlight factors contributing to the success of the project.

L. Stephen M., M. Locke S. and L. Bracey G..
Using a Participatory Design Approach to Create and Sustain an Innovative Technology-rich STEM Classroom - One School's Story.
DOI: 10.5220/0004849900300038
In *Proceedings of the 6th International Conference on Computer Supported Education* (CSEDU-2014), pages 30-38
ISBN: 978-989-758-022-2

2 BACKGROUND & VISION

The newly constructed STEM classroom is a part of McCoy High School, a public high school located within the local city public school district and sponsored by a nearby public university. The school is located in an economically depressed, post-industrial, Midwestern city which is part of a large urban metropolitan area. All of the school's 115 students are African-American, and approximately 90% of students are eligible for free or reduced-price lunches. The school has limited resources and, prior to construction of the STEM classroom, had access to only two outdated computer labs that often were not fully operational. The school recently completed a third year on academic watch. In the United States, a school is placed on academic watch if it does not meet proficiency performance standards in academic, attendance, and graduation rate targets defined by the state for four consecutive years.

Students in districts with a high poverty level are especially at risk of being unprepared for university science and mathematics courses (Darling-Hammond, 2010). As students advance in grade level, mathematics and science test scores markedly decline. In the McCoy High School district, only 47% of 7th graders and just 8% of 11th graders meet performance standards for science on state examinations. Furthermore, schools in low-income communities often do not have the materials, laboratories, and equipment to teach mathematics and science effectively, and many teachers lack the necessary training in their subject areas.

In early 2011, the university received a large donation to design and construct a high-technology STEM classroom at the high school, with some of the funds designated for teacher professional development and onsite technology support personnel. The university's STEM Center was charged with overseeing the classroom's design and construction, and it played a key role in gathering together the design team and establishing the project's vision.

The overall vision for the new classroom was developed by experts in STEM education at the university. The stated purpose of the new learning space was to provide students with access to state-of-the-art technology, equipment, and curricula and to support teachers in providing students with hands-on, minds-on science learning. Then, taking a wider view, the team envisioned the classroom as a resource for the entire school district and as a model for excellence in STEM education far beyond the local setting.

The largest portion of the classroom was viewed as a "learning studio," in which movable, flexible seating would enable group work and student-centered discussion. Integrated into the physical space would be state-of-the-art computing and communications technologies and scientific equipment, providing opportunities for authentic learning rarely afforded in low-income communities.

The team also proposed a separate, smaller facility adjoining the main classroom, modeled after the fabrication laboratory, or "FabLab," concept. Originating at the Massachusetts Institute of Technology, educational FabLabs allow students to design objects on a computer using CAD software and then see their creations printed in three-dimensions. FabLabs enhance the learning of a variety of subjects ranging from geometry to engineering, to art and design, and help students see the connections between STEM and the creative process (Blikstein, 2013). Another goal for the space was to enable teachers to move easily between the main classroom and fabrication area as needed to ensure student engagement and achievement of learning goals.

A final, yet essential, component of the project was the provision of teacher training and support to ensure that the STEM teachers would be fully empowered to integrate the new resources into their teaching. It was intended that university faculty, master educators, and an on-site educational technology specialist would work in partnership with the high school teachers over an extended period of time to ensure that the technology and equipment would be used effectively and with the greatest benefit for student learning.

3 DESIGN PROCESS

The design process for the STEM classroom was participatory, using input from multiple units within a university, business representatives, and the ultimate users of the space, the school's teachers and students. Participatory design was initially introduced in the design of computer systems and technologies in the early 1970s. Today, the concept of participatory design is more flexible and applicable in a range of fields employing a variety of techniques (Crabtree, 1998). A major constant in participatory design is the involvement of users in the design process. According to Baek & Lee (2008, pp. 173), "a participatory design process relies on the collective generativity of stakeholders; in other words, it uses the collective ability of stakeholders to generate or create thoughts and imaginings."

The classroom design and construction involved a large team of individuals representing several units of the university and three businesses. The university's STEM Center director articulated the vision for the space through team meetings, and each unit took responsibility for different aspects of the design. The university's Instructional Technology Services (ITS) assigned two representatives to develop plans for configuring the room to maximize the use of computing technology. Installation of computer projection and videoconferencing systems and networking capabilities was completed by an outside contractor. The university's Facilities Management assigned an architect to design the physical space and to manage the construction schedule and work of carpenters, painters, and electricians.

At an early stage, the university contacted Herman Miller®, known for their innovative furniture designs and interest in research on learning spaces, to request that the project become part of Herman Miller's Learning Studio Research Program. Consequently, McCoy High School became the first secondary school accepted into this program. This formal partnership brought additional resources to the project including interior design expertise. Herman Miller® and an interior design company worked with the project team to turn the vision into reality, providing possible room plans, furniture options, and color schemes.

The participatory design process ensures that all users play a meaningful role in the design as "either an informant or co-designer" (Bowen, 2010) in order that the end result will better meet their needs and uses. Diverse perspectives, especially those of teachers and students, are important when designing educational environments (Könings et al., 2007). According to Woolner (2009, p.15), "Importantly, it seems that the potential for longer term influence is bound up with recognising and understanding the inextricable linking of actor and setting, as this applies to the wide range of school users throughout and beyond the period of change. If this shared understanding can be developed through participatory design, this should satisfy the needs of architects and educationalists (e.g., Dudek, 2000 and Clark, 2002, respectively) who have called for more involvement of users in school design and recognition of the practical contribution of the physical setting to teaching and learning."

Thus, a critical aspect of the process of designing the STEM classroom involved participation by its end users. The school's three STEM teachers and six student representatives provided feedback on their needs and their vision for an effective learning space. Meetings of the STEM Director and the high school team explored teachers' and students' opinions on everything from the educational activities that would take place in the space to possible designs to the aesthetics and feel of the learning environment. Feedback was summarized and conveyed to the larger group and incorporated into the design whenever feasible. A summary of key comments from the teachers and students is shown in Figure 1.

Space and Furnishings
- Colorful
- Bright lighting
- Movable furniture for flexible seating arrangements
- Café-height chairs

Technology
- Work spaces for robotics and other design tasks
- High-speed wireless
- Many electrical outlets
- Separate printer room to reduce noise levels
- Experimental technologies
- Durable equipment

Teaching Environment
- Communication is facilitated by multiple writing surfaces
- Open spaces to move in and form student groups
- Option of two instructors/classes in the room simultaneously
- Respectful attitude towards the room and equipment

Figure 1: Teacher & Student Comments.

Four overarching principles guided the design team and are reflected in the final product:
- Fosters creativity and innovation
- Meets the needs of the school
- Appeals to students and teachers
- Integrates innovative technologies

The next section focuses on how these principles are reflected in the final design of the classroom.

4 CLASSROOM FEATURES

The overall design of the classroom encourages student-centered instruction and group work. The room contains a variety of tables and chairs that are easy to reconfigure for large and small group activities. Movable whiteboards and writable walls provide a large amount of writing and design space (Figure 2).

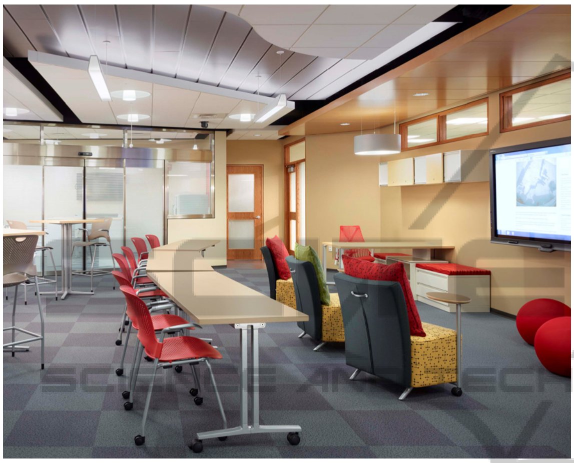

Figure 2: McCoy High School STEM Classroom. Photo courtesy of HermanMiller®.

Computer and information technologies are central to this learning environment (Figure 3) and can be easily configured for independent and group projects. Laptop computers and tablets can be plugged into the network via floor ports in multiple locations throughout the room, and in turn can be projected onto one of several screens. Additional technology features of the room include a four-screen video wall, an LCD SMART Board, 52-inch TV monitor, HD document camera, and ceiling-mounted video cameras to record classroom activities. Sets of iPads, laptops, Botball robotics kits, a programmable humanoid robot, TI-Nspire calculators, and student response systems are available for individual and collaborative work. Additionally, the FabLab contains a 3-D printer and computers with design software to enable students to work with engineering design projects.

The first meeting to begin the design process was in April 2011, and the ribbon-cutting and official opening of the STEM classroom took place in February 2012. In late 2012, The Educational Interiors Showcase awarded the STEM classroom one of its top awards for classroom design, noting the space’s “good use of technology" and its "variety of collaboration/presentation spaces and seating options within the classroom.”

- Laptop computers
- iPads
- Graphing calculators
- Robotics kits
- Humanoid robots
- Digital cameras
- Document camera
- Multiple flat panel displays
- Video wall
- Classroom recording system
- High definition video conferencing
- 3D printer
- Large format printer
- Desktop computers with 3D design software

Figure 3: STEM Classroom Technologies.

5 IMPLEMENTATION

Teaching practice is a product of both the teacher and the teaching environment (Wilson, 2011). Once the room design was completed and construction started, teachers began to consider the question of what they needed to learn in order to make effective use of the new technologies for teaching and learning. They realized that using the technologies within the new space could not only impact current practices, but would require teachers to be open to changing the way they currently teach.

5.1 Researching the Implementation

In conjunction with the design and implementation of McCoy's STEM classroom, researchers from the University’s STEM Center designed a research study to understand and document how the STEM teachers capitalized on the potential of the space and available technologies to adopt new or modify existing pedagogical strategies. The research explored factors and challenges that influenced when and how teachers use the room and its technologies. This included examining teachers’ concerns and attitudes about using the space over the course of its implementation. It was hoped that findings from this research could be used to optimize the usability of the learning space.

Because of the uniqueness of this complex and dynamic setting, the researchers chose a single case-study design with mixed methods of data collection and analysis. The intention in using this design is that the story developed may provide unusual insights that challenge or reinforce a reader's existing beliefs and promote broader understanding of the issues involved (Patton, 1990; Stake, 1998; Yin, 2009).

Two of the math and science teachers at the school agreed to participate in the research study. Initially, the study followed three teachers; however, one of the teachers left McCoy High School shortly after the research study began. Demographically, the two teachers who are the focus of the study are very different. Teacher A, an African American female in her 60s with extensive experience as an IT professional, participated in the design meetings. She had taught for five years at McCoy High School at the time the room was designed. Teacher B, a Caucasian male in his 20s, also participated in the design meetings. He recently had been hired and began his first year of teaching during the year the room was constructed. In addition, two key administrators at the school agreed to participate through interviews, and 30% of the students agreed to participate through focus groups and by completing surveys about the features of the room, the technologies, and their teachers' teaching styles.

Data sources include guided and open-ended interviews with teachers and administrators, student focus groups, and observation of sessions in both the STEM classroom and in regular classrooms. Additional data that inform the study were gathered from survey instruments including pre and post student and teacher questionnaires designed as part of the Herman Miller® Learning Spaces Research Program and periodic administration of the Stages of Concern Questionnaire (SoCQ) (George et al., 2006) to STEM teachers. SoCQ is used to create profiles of individuals' evolving levels of concern throughout the process of adopting an innovation.

The data enabled the researchers to identify challenges encountered by the teachers when using this new space and when incorporating new technologies and pedagogical strategies into their teaching. The following section identifies these challenges along with ways these challenges were approached.

6 CHALLENGES TO IMPLEMENTATION

1. *Lack of Familiarity with Many of the Technologies Available and ways they might Effectively be Integrated into Teaching*

Approach: Numerous researchers have identified teachers' confidence and skill in using technologies combined with ability to see value in using technologies as major factors influencing teacher adoption of available technologies (Bingimlas, 2009; Buabeng-Andoh, 2012; Gaffney, 2010; Mumtaz, 2000). One way to build teacher confidence and skill is through professional development. Effective professional development is ongoing, uses peer coaching, and includes teachers in planning activities (Garet et al., 2001; Gulamhussein, 2013).

At McCoy High School, professional development began during the construction phase and continues today, with the STEM teachers playing a leading role in identifying the type and pace of the activities. Because of other demands on their time, the teachers asked that training focus on one new technology at a time. This would enable them to become familiar with the technology and consider how best to use it with students.

The teachers visited other schools' high-tech classrooms and participated in national conferences, such as the National Science Teachers Association (NSTA) and International Society for Technology in Education (ISTE), as they sought ideas for using the new technologies in their own teaching. Vendor demonstrations occurred, and teachers were given iPads to familiarize themselves with the technology and begin to plan how they might use them in teaching. Teachers from other schools who were experienced with particular technologies led hands-on sessions to introduce teachers to new technologies, such as TI-Nspire graphing calculators and 3-D printers, and shared information on ways they use the technologies with students. An education faculty member from the university worked with the teachers to develop and test lessons incorporating the new technologies and features of the space. Teachers observed and critiqued the lessons for each other. These master technology teachers along with university personnel are an ongoing resource for the teachers.

2. *Need for Regular Communication Among a Diverse Group of Stakeholders. Stakeholders Included the School Director, STEM Teachers, University Personnel and Researchers*

Approach: According to Rogers (1962), effective communication channels play a central role in the diffusion of innovations. Communication and sharing of information among the stakeholders involved in the implementation phase proved at times to be problematic as other responsibilities and duties took precedence and delayed email or phone responses. To ensure that all stakeholders are informed on issues related to use of the STEM classroom, periodic meetings occur with key school administrators, STEM teachers, STEM Center director and researchers, and a representative from the University's education department. Albronda, De Langen, and Huizing (2011) report that group meetings appear to be an "effective means of informing and interaction" among stakeholders during adoption of an innovation. The meetings, which are ongoing, provide an opportunity for sharing information, celebrating successes, discussing issues specific to the STEM classroom, planning ways to address STEM teachers' professional development needs, identifying teachers' needs with respect to the STEM classroom and the technologies, scheduling research observations and interviews, sharing of school initiatives by school administrators, and discussing how teachers are using the space and technologies.

3. *Limited Technical Support*

Approach: "Because technology is inherently unreliable and can break down at any time, teachers may choose not to use it in their teaching unless there is a strong need for it and reliable support" (Zhao and Frank, 2003, p.809). Although teachers and school administrators had input regarding the choice of technologies for the space, the university completed the purchasing and installation. As the teachers began to use the technologies during their first year in the new space, Teacher B, who had a reputation for being able to fix technology problems, assumed the role of technology support person in addition to his teaching responsibilities, and described this role as a "burden." However, during the second year, the university hired a part-time technical support person--again with teacher input--to keep the equipment running and provide just-in-time assistance when the classroom is in use.

4. *Classroom Management Issues*

Approach: A major concern of the teachers was how to handle behavior problems and prevent damage to the technologies in the new space. One teacher addressed this by only bringing upper division students into the space during the first year and limiting the features and equipment that could be used. The teachers developed some general rules that all users agreed to abide by with respect to putting technologies properly away at the end of sessions and keeping the space clean. Participants in student focus groups described how they felt responsible for keeping the room and the equipment in good condition. One student responded to the question, "Who takes care of this room?" by saying, "I feel like we all do. I feel like it's a community effort... everybody kind of contributes to cleaning up the room."

5. *Equitable use of the Space*

Approach: As STEM teachers began to bring their classes into the new space, concerns developed around the fair and practical use of the room. Even though a listing of time slots was made available as a sign-up sheet on Google Docs, one teacher tended to monopolize the schedule so other classes were rarely able to use the room. If a time slot was empty, other STEM teachers would often move their classes in without signing up, resulting in two classes arriving at the room at the same time. Together, the teachers developed a protocol to ensure that each student in the school uses the space and its technologies at least once a week, and that every STEM class has a lesson taught in the classroom every week. They devised a better way of scheduling their time in the classroom, and even found ways for two classes to occasionally use the space simultaneously. Also, technologies such as iPads, laptops, and calculators can be used in a teacher's regular classroom when not needed in the STEM classroom.

6. *Professional and Personal Concerns*

Approach: The time required to keep up with rapid changes in technology is an important factor in its use (Zhao and Frank, 2003), and teachers often worry about how to do this in addition to their other teaching duties. For example, Teacher A identified "other responsibilities/priorities and time to learn" as major obstacles to implementing new technologies. There also appeared to be a question of what personal value the new technologies would have. "Personal feelings of uncertainty, whether one can succeed with this innovation, and whether the supervisor will support the efforts," are common concerns of teachers faced with adopting an innovation (Hall, 2010, p. 243). Teacher B found balancing responsibilities of being a first-year teacher, assuming the role of the school's IT specialist, and exploring what teaching with new technologies would require from him to be challenging.

Several aspects of the implementation process addressed these concerns. First, the school provided time and substitute teachers, giving the STEM teachers opportunities to visit other high-tech schools and to attend conferences. Other events such as an open house and various newspaper articles celebrated the STEM classroom and its success, giving the teachers and students a sense of pride.

Teacher A commented, "There's a lot of visibility... I think kids were proud to see us in the paper. I think it's always good to highlight the good, and so I think that overall it's been a really positive thing. I get more positive all the time."

7 DISCUSSION

Using a participatory design process that included students as well as teachers has led to a sense of ownership of the room by both groups. Teachers and students depict traditional classrooms as 'teacher space' while they view the STEM classroom as 'community space' with both teachers and students equally responsible for maintaining the room. In focus groups, students enthusiastically discussed how pleased they were to see their suggestions integrated into the actual classroom along with ideas they had not even considered, such as the video wall. On their own initiative, they have created projects relating to the use of the room and its technologies as a "legacy" for future students.

One major aspect of the room that both teachers and students praise is the room's flexibility. The furniture can easily be rearranged to accommodate different teaching styles and activities. Students appreciate being able to display their work in different ways using a variety of devices. Teachers regularly comment on students' pride in the room and how being in the room seems to positively affect students' willingness to stay on task and learn.

The room appears to be having an impact on teachers' teaching style as well. Teachers describe their teaching approach in the STEM classroom as being 'less dictatorial' and more relaxed than when they are in a traditional classroom. One STEM teacher who had been somewhat reluctant to use the technologies in the room observed that anticipated classroom management problems did not materialize to the extent expected. Consequently the teacher became more open to identifying technologies in the room that might be used next in teaching. In the STEM classroom, this same teacher encouraged students to learn new features of technologies and share their expertise. The other STEM teacher described how having so many different technologies available made it easier to accommodate students' different. Although the teachers are not yet using all of the available technologies, it is anticipated that all will be in use by the end of the second year in the room.

The design and implementation process for the STEM classroom is ongoing. Often stakeholders' involvement ends once construction has been completed. However, an important aspect of the process described in this paper is that university and STEM Center personnel continue to be actively involved during the implementation phase in a variety of ways, including participation in the periodic meetings, facilitation of professional development requests, and continuation of the research study. The presence of a technology specialist has alleviated technological problems and allowed the teachers to focus on ways to integrate the technologies into teaching and learning. Administrators and STEM teachers continue to identify additional resources needed in the room and in their professional development. The room itself was not designed to be static, but rather to continue to evolve as users experiment with different ways to teach and learn in the space. The presence- of mobile technologies in particular will enable upgrading the technologies as newer devices become available.

One final consideration is the importance of leadership. Byrom and Bingham (2001) identified strong, supportive leadership as one of the most important factors in teachers' willingness to adopt innovations. The leadership role played by stakeholders from the university--especially the Director of the university's STEM Center--was crucial during design and construction of the classroom and continues during implementation.

The leadership of McCoy High School also played an important role. The construction and implementation coincided with the appointment of a new director for the school. In discussing the room, the director stated that continued student input would be very important to the success of the room. She stressed to the teaching staff that because the room contains the best and the latest of technologies, activities within the STEM classroom should be project-based, utilizing the technologies and features of the room to the fullest. She emphasized the importance of seeking out appropriate professional development to achieve this goal. Throughout the implementation process she has encouraged the teachers to decide how best to use the space and technologies and to play a major role in designing the content and pace of their professional development. She has arranged substitute teachers when these activities conflicted with their teaching schedules.

The director takes great pride in the room and has made it integral to setting future priorities for the school. She has been instrumental in publicizing to parents, community members, media and university personnel what teachers and students are accomplishing in the room. In describing the impact on the students, the director said of the STEM classroom it will "...change lives. We have an advantage of educating minority and underprivileged students with this advanced technology. They are going to have more options because of the STEM experience at the high school level."

The successful implementation of a technology-rich educational environment requires a participatory process that doesn't end when construction is complete. Keeping the stakeholders actively involved and attending to the concerns of the teachers and students greatly increase the usability and sustainability of this type of project.

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