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Making "Wild Sound": A Case Study in Engineering and Musical Performance Co-Design

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Abstract

This paper describes and analyzes the development of Wild Sound, a musical work composed by Glenn Kotche and performed by Third Coast Percussion, with custom instruments designed and built by engineering students at the University of Notre Dame, that has been performed for national audiences. Using theories of design from Simon's *Sciences of the Artificial* and current views of *Design Thinking*, the paper examines the complex multidisciplinary design process behind the development of this work. It also examines the learning experiences of the design team and suggests ways that future academic design projects may benefit from this experience.

Introduction

"Wild Sound" has been described as challenging "the distinctions that exist between music and noise, instrument and everyday object, performance and daily life.[1]" Written by modern classical composer Glenn Kotche—who is also the drummer for the Grammy award-winning rock band Wilco—and performed by Chicago-based percussion ensemble Third Coast Percussion, the 45 minute extended work "Wild Sound" features custom instruments that were designed by a team of faculty and undergraduate students at the University of Notre Dame, simultaneously with the composition of the piece and the choreography of the performance. Since its premier at the Notre Dame DeBartolo Performing Arts Center, Wild Sound has also been performed at the St. Paul (Minnesota) Chamber Orchestra and has scheduled performances for spring 2015 at the Chicago Museum of Contemporary Art and the Metropolitan Museum of Art in New York City.

The purpose of this paper is to provide a formal analysis of this fascinating co-design process using an engineering design framework that considers objectives, constraints, multidisciplinary decomposition, and iteration across the engineering, musical composition, and performance domains. It considers the applicability of two theories of design, the work of Herbert Simon from the 1960s presented in his seminal monograph, *The Sciences of the Artificial*[2] and *Design Thinking*[3] that is currently much in favor in design education. The research methodology involved interviewing the participants in the project and asking them a series of questions. Responses were then mapped to elements of the models. In performing such an analysis, the paper seeks to provide insights into the conduct of a complex multidisciplinary design project that may lead to improvements in the design process for future projects.

The remainder of the paper is organized as follows. First, it provides an overview of the Wild Sound project. Next, it summarizes the relevant theories of design. After this, it provides excerpts of the interviews of participants, including the composer, the performers, and the student engineers, and then maps observations from the interviews to the design theories. Following this, the paper provides reflections from the participants on what they learned from the project, as well as suggestions from the students regarding further development of classes that integrate engineering and the arts. Additionally, results of a survey of audience members on their reactions are cited. The paper closes with conclusions and future work.

Overview of Wild Sound Project

The making of Wild Sound began approximately five years ago, when Third Coast Percussion approached composer Glenn Kotche regarding the possibility of commissioning a work from him. That possibility became a reality in 2012 when Third Coast began a 5-year tenure as artists-in-residence at the University of Notre Dame, where the university, with several other partners, decided to fund this commission. At that time, composer Kotche had a kernel of an idea for the work: to explore the relationship between "wild" and "tamed" sounds, the distinction between noise and music, and between musical performance and theater. The concept also included the notion of constructing musical instruments on stage, where the sounds of the construction were part of the score, and then playing the instruments.

Figure 1: Scenes from Wild Sound, top to bottom, left to right. Constructing primitive instruments from scratch in Part 1, "Wilderness;" playing music with sticks in a foam block, amplified by a piezo contact microphone embedded in a meat thermometer during Part 2, "Rural;" playing a reciprocating saw with attached electric guitar pickup in Part 3, "Industrial;" playing Arduino-based synthesizer keyboard with conductive fabric gloves in Part 4, "Modern".

The narrative arc of "Wild Sound" celebrates the evolution of technology from rural to modern industrial times. It has four distinct sections or movements: "Wilderness," "Rural," "Industrial," and "Modern," illustrated in Figure 1. As part of the performance, non-traditional instruments are constructed on stage, where the sounds of the construction are part of the musical score. The custom instruments include acoustical instruments that are shaped with hand and power tools, an "audience participation" instruments mass-produced with a laser cutter, embedded piezo contact microphones, and a variety of MIDI synthesizers designed using Arduino processor technology. A team of faculty and 6 undergraduate summer research interns performed the design of the electronic instruments. The complete "Wild Sound" performance also includes a video track projected behind the stage and an ambient audio track with "found sounds" that Kotche collected while on tour internationally with Wilco, and real-time adjustments by an audio engineer.

Theories of Design

Simon's Sciences of the Artificial

In a series of lectures from the 1960s, published in the monograph *The Sciences of the* Artificial[2], Herbert Simon noted two classes of objects and phenomena in the world: natural objects and phenomena made by the processes of nature, and artificial processes, made by mankind. Corresponding to these, the business of the natural science—such as chemistry, biology, or physics—is to study natural processes, while the business of the artificial sciences—including engineering—is to study those things "made by human work or art[2]". Artifacts can have many different kinds of purposes and forms, ranging from hard goods such as musical instruments, to processes such as protocols for conducting an experiment, to events such as a musical performance. According to Simon, whereas the natural sciences primarily seek to discover how things *are*, the artificial sciences seek to discover how things *should be*, to serve a particular human need. In the *Sciences of the Artificial*, Simon goes on to examine models for how people design artifacts—giving form to purpose—such that they will effectively serve their desired purpose in a given environment. This section summarizes a few of the key elements of Simon's models for design, such that they can be used to obtain a better understanding of the process of designing the Wild Sound production.

A key aspect of Simon's model is his view of the environment as a "mold" for a design—one that constrains the final form that an acceptable design may take. As pictured in Figure 2, this mold has two parts, inner and outer, and an acceptable design may be thought of as a thin band that fits between the two.

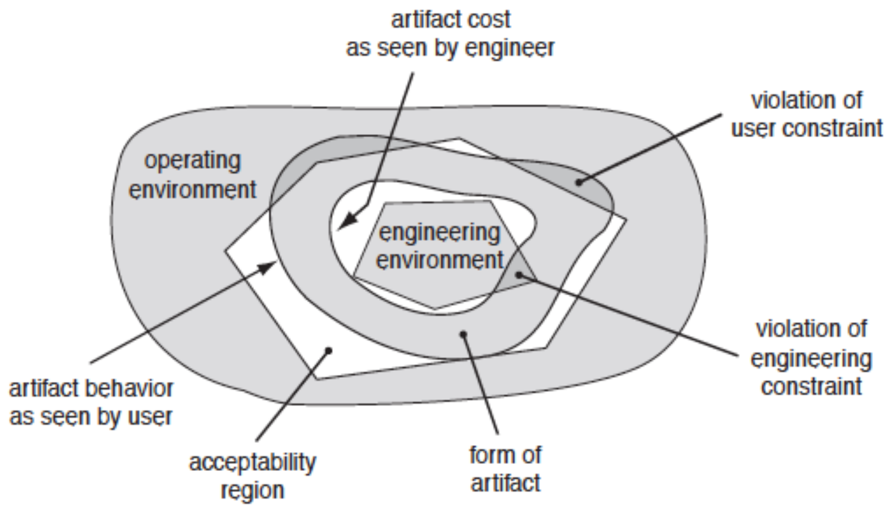

Figure 2: The environment as "mold" for a design[1].

The outer part of the mold, the outer or operating environment, represents those constraints that are external to the design team. In the case of Wild Sound, for example, this would include the audience's experience with the design. This inner or engineering environment represents constraints on the resources available to the design team, including materials and their own skills and tools. A design is deemed acceptable if it fits between these two environments without violating any constraints. The design process itself may be viewed as a system of forces pushing and pulling on the form of a design, attempting to make it fit within the environment. Simon discusses a variety of methods by which this may be accomplished, but in general, most such processes are highly iterative in nature.

A second aspect of Simon's model is that independent of the type of artifact—be it a hard good, a process, or an event—many artifacts exhibit a common internal organization of readily identifiable subcomponents, a "boxes-in-boxes" or hierarchical organization as an interconnected system. He posits that one reason for this is that the "shape" of an artifact's organization reflects the nature of the human thought processes behind the design process. In short, human problem solving typically involves breaking complex problems down into simpler ones, and the artifacts that we design bear the imprint of this problem solving approach. As an example, Figure 3 shows a concept map[5] illustrating the organization of subsystems and subcomponents in an automobile.

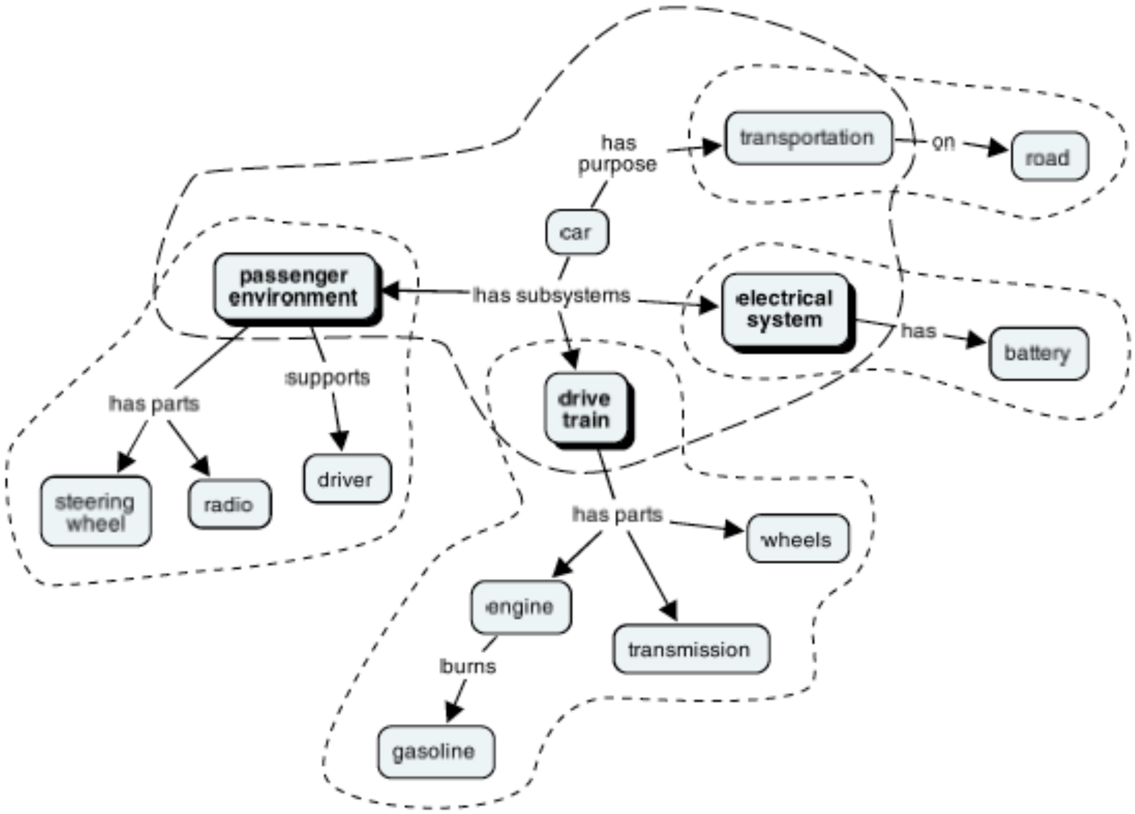

Figure 3: Concept map of the hierarchical organization of components in an automobile[1]

Design Thinking

Design thinking[3] is a prescriptive theory of design that has gained great popularity in recent years as a practical approach to effectively determining the needs for a design, and then iteratively developing a working prototype. There are many different formulations, but at its core, it is a human-centered process that begins with identifying human needs. Work done at Stanford University and the design firm IDEO—itself an outgrowth from Stanford—has played a very significant role in the adoption of this methodology[6]. The Stanford d.school design thinking methodology lists five steps, summarized below:

- **Empathize:** observe and engage with potential users of a design to determine their needs
- **Define:** use the observations from the empathize step to formulate a user point-of-view as an actionable problem statement
- **Ideate:** generate a wide list of design concepts that address the problem statement from the user point-of-view, for example through brainstorming.
- **Prototype:** generate inexpensive, rapid prototypes of candidate design solutions for the purpose of testing their adequacy to solving the design problem. These are explicitly *not* intended to be complete working designs, merely implementations that give body to the results of ideation.
- **Test:** solicit feedback and identify shortcomings of the prototypes. Prototypes are *expected* to have shortcomings—a common mantra regarding the testing of prototypes is to fail early and cheaply.

Data Collection: Interviews with Project Participants

In preparation for testing the relevance of the theories of Simon's *Science of Design* and the Stanford model of design thinking to the making of Wild Sound, we conducted a series of interviews with the composer Glenn Kotche, the Third Coast Percussion performers, and with the engineering students that were on the instrument design team. The interviews were conducted by telephone in a somewhat interactive manner, with some follow-up, clarification, and additional probing by the interviewer. The interviews were recorded and transcribed, and the responses were analyzed and keyed as pertinent to each of research questions. The framework for the interviews was built around the following four questions:

- How would you define your role in the Wild Sound project and what was the purpose of what you did in the project?
- What were some of the environmental or contextual factors that helped shape the way that your part of the project turned out?
- In what ways did you break down the over problem of developing your part of the project to make your work more manageable?

Interview transcripts were then analyzed for common themes, both within and across interview questions.

Findings from the Analysis of Interview Results

Relation of Simon's Sciences of the Artificial Model to Wild Sound

To determine the relevance of Simon's model, we looked for answers to two key questions in the survey responses.

- What are the artifacts and the relationships between them in the organization of the project as a whole? What was the use of hierarchy?
- For these artifacts, what are the purpose and inner/outer environmental factors that shaped their form, from the perspectives of the composer, the performers, and the engineering team?

The first question, what are the artifacts in Wild Sound and how are they related, was surprisingly difficult at first to answer in a meaningful way. Certain artifacts were obvious from the outset, such as the musical score created by the composer or specific instruments created by the engineering team. However, there were other *non-obvious* artifacts that were determined to be necessary and that had to be invented after the project began that played a critical role in the overall success of the project. The purpose of these artifacts was typically to connect or organize other artifacts in the system. Ironically, while the design of these non-obvious artifacts consumed significant design time and effort, while they were being designed, the team was not aware of them as artifacts in their own right. In fact, their significance only became clear as a result of answering the second question, namely understanding the constraints of the inner and outer environments as perceived by the different participants. For this reason, we will first consider the question of environment and then return to identifying the artifacts and their relationships.

Each of the participants had different perspectives on the inner and outer environments, summarized in Tables 1-3. A fact that became immediately apparent from analyzing the interviews was that each of the participants had *constraints due to artifacts that were being designed by other participants*, as well as constraints that were external to the design team as a whole. For example, from the perspective of the engineering team, the specific set of notes and sounds written into the composition constrains the design of the instruments. As one student on the engineering team said,

> *"One of the biggest technical challenges in designing the electronic instruments was dealing with the number of different inputs that an instrument could potentially have, as well as the accuracy needed to produce individual notes. We needed to be sure that Third Coast could accurately produce these notes from the instruments. The original Arduino Uno boards we used only had a limited number of physical inputs and we had to look at different schemes like multiplexing or moving to different Arduinos with more pins. Once we saw the actual score for the piece, it cancelled out some of our early ideas and focused on others."*

Such a constraint could be considered as part of the external environment of the engineering team, but because they have the opportunity to modify this constraint through a negotiation with the composer, it was instead classified as part of the internal environment.

Table 1: Constraints from composer's perspective

Environmental Constraints from Composer's Perspective	
Inner Environment	**Outer Environment**
Composer's own innate creativity	Does something have musical value? (aesthetic constraint)
The time to construct the instruments (constrains pacing of the music)	Safety to performers
The palette of sounds available from practically realizable instruments	Safety to audience and venue, possible damage to stage
	Overall duration of the piece
	Economy (production has to travel)
	Scale, size of instruments (must fit on stage and be able to be moved and assembled by performers)

Table 2: Constraints from engineering perspective

Environmental Constraints from Instrument Engineers' Perspective	
Inner Environment	**Outer Environment**
Learning curve: none of the team members had designed electronic instruments before and very limited experience with Arduinos	"Maker Aesthetic:" stay true to the spirit of Wild Sound, sophistication of design of electronic instruments should be on a par with other made instruments
Instruments must fit on the stage set, for example in racks or on existing table tops.	Musicians' ability to play the instruments, ergonomics
Maximize use of off the shelf parts, try not to "reinvent the wheel."	Reliability/robustness/reparability
Use Arduino as microcontroller for all designs, along with available shields where possible	Portability and roadworthiness
Minimize cost	
Willing to do 1-2 custom printed circuit boards if necessary	
Minimize the number of unique artifacts to be designed, try to reuse where possible	
Must be able to produce the notes that the composer requires	
Must be able to "shape" the amplitude/loudness of notes (attack, sustain, decay) in the manner that the composer requires	
Desired voicing/timbre, palette of musical colors/sounds	

Table 3: Constraints from performers' perspective

Environmental Constraints from Performers' Perspective	
Inner Environment	**Outer Environment**
What they have experience and comfort with and what not as musical performers	Audience must have an engaging experience
Set of physical instruments with which they could produce musical notes during a performance	Stay true to composer's artistic vision
The performers need to be able to know which actions to perform when (stay in sync with each other and with the audio and video tracks).	Make sure that actions performed contribute to musical value (aesthetic constraint)
	Safety to performers; Safety to audience and venue
	Overall duration of the piece
	Economy (production has to travel)
	Scale, size of instruments (fit on stage)

Analyzing the results of Tables 1-3, it is clear that there are a number of constraints that derive from a portion of the overall project that is being designed by another participant. Two especially significant constraints of this type are:

- The time that it takes for the performers to build the instruments has a profound impact on the pacing of the overall piece, which constrains the design of the musical composition, the audio track, and the video track, which must all be in sync with each other.
- The set of musical tones that the instruments must produce constrains the design of the electronic instruments. The instruments must be designed in such a way that the performers can ergonomically trigger the right sounds at the right time (in tempo), while the layout of the instrument controls must fit the physical constraints of the stage, such as fitting in racks or on table tops.

So important were dealing with these two sets of constraints that finding a way of managing them *became design problems in their own right*, each of which produced innovative artifacts, although the team did not explicitly view this as such at the time. These two non-obvious artifacts may be defined as:

- **Timeline Management Scheme:** a process for determining the timing of actions, and encoding them in the score such that the performance stays in sync
- **Tone Patches:** a means for bundling sets of musical tones that are implemented in the Arduino instruments, can be easily called up and triggered by the performers, and that can be represented in the score.

Figure 4 presents a concept map of the artifacts surrounding the time management scheme. The extensive set of time study experiments informed the design of the overall performance timeline. A key innovation was that the cues for performing different actions, be they starting or completing the construction of instruments, playing a section of the fixed musical score, or performing a musical improvisation, were all effectively encoded within the audio track, e.g. "start sawing the wood when you hear the train sound." While the concept for the audio track began as a sonic backdrop of found sounds, it was later also repurposed as an effective means for keeping the entire Wild Sound performance in sync.

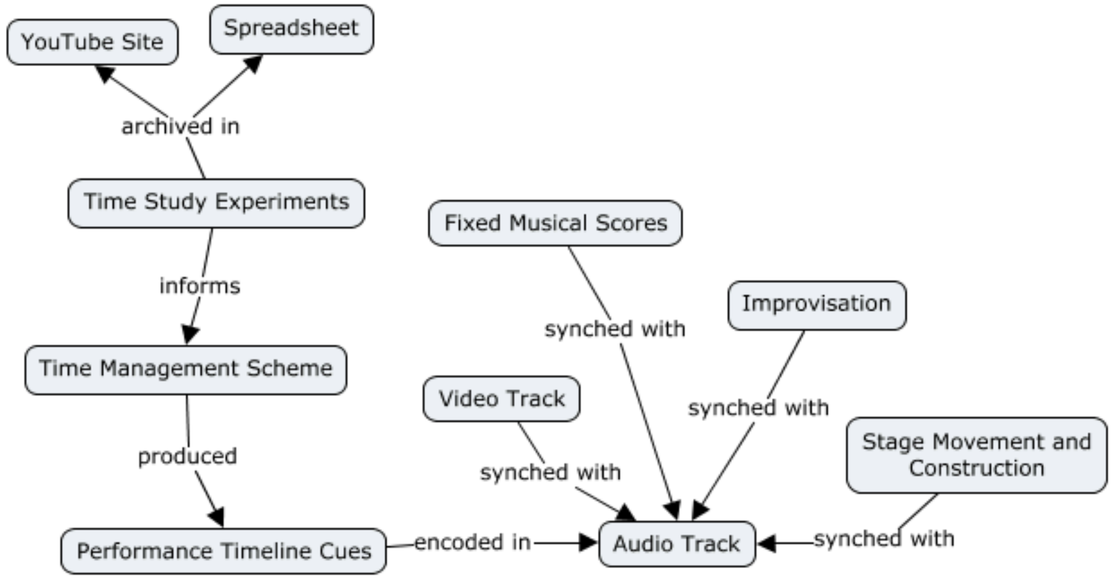

Figure 4: Concept map of artifacts surrounding time management scheme.

Figure 5 shows a concept map of the artifacts surrounding the design of the tone patches. Each tone patch contains a discrete set of musical tones of different pitches, having a common timbre and amplitude envelope (musical voice). The patches were derived from a careful analysis of the musical score, to identify sets of notes that are played for an extended period before switching to another set. Internally, the Arduino MIDI instruments contained two main components: a tone generator (synthesizer) and an interface with sensors that are manipulated by the performers to play music (controller). Figure 6 illustrates the Arduino MIDI controller/synthesizer box. A knob on the controller allowed the performers to switch tone patches. Standard RJ12 phone jacks are used to connect the controller system to the physical instrument using standard 6-wire phone cables. Depending upon the instrument, a variety of sensors are used in the instrument to trigger notes when struck or touched.

The innovation of the tone patch worked extremely well as a means for representing musical tones between the performers and the instrument designers: for example, although the score for the four part of Wild Sound ("Modern") spanned six octaves of rapidly played notes, using patches, the engineers were able to design clear acrylic keyboards, shown in Figure 7, with only 23 washers as keys that would comfortable fit in the 3 foot wide racks, with key spacings that could be comfortably played by the performers, infrequently switching patches as needed. The identical system of tone patches and physical connectors was used to interface to the MIDI enabled xylophone and glockenspiel used in the third part of Wild Sound, shown in Figure 8.

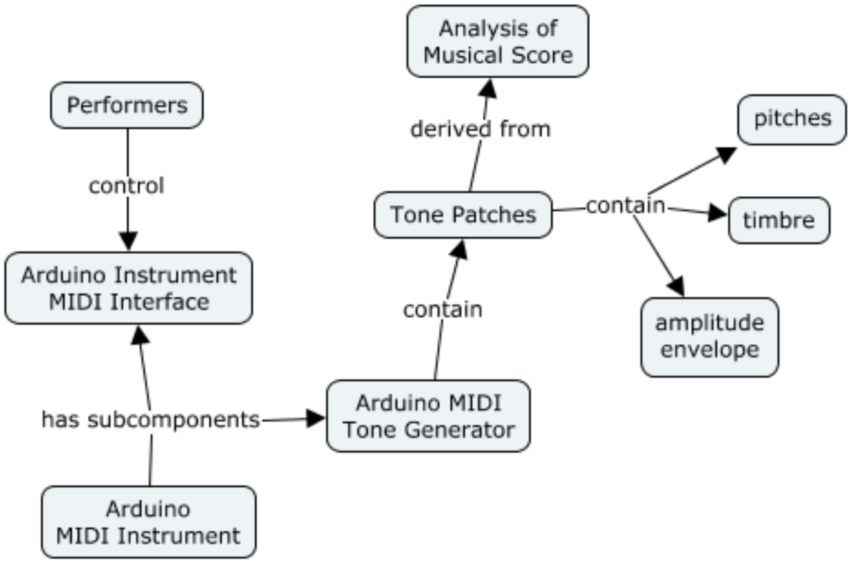

Figure 5: Concept map of artifacts surrounding tone patches

Figure 6: Wild Sound Arduino/MIDI controller and synthesizer. System is implemented as a stack of 3 circuit boards, Arduino MEGA 2560 on bottom, custom Wild Sound interface board in middle, and SparkFun Music Instrument Shield on top. A rotation encoder is used to switch between tone patches. RJ12 phone jacks provide an interface to up to 16 analog input and 34 digital input/output signals on the musical instrument control surfaces.

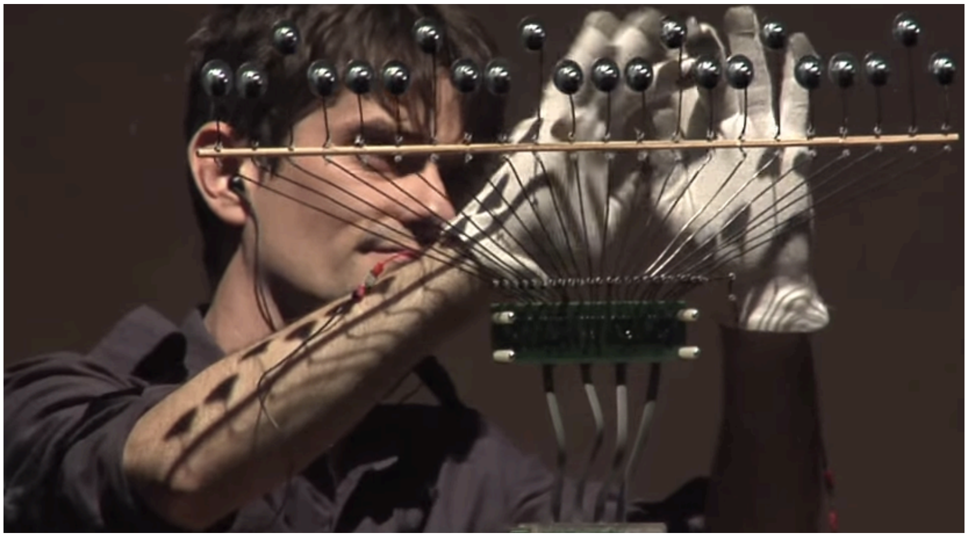

Figure 7: Clear acrylic keyboard used in performance of fourth part of Wild Sound. Conductive fabric on the fingertips of gloves worn by performers close a circuit formed with bolts and washers as keys. Standard 6 conductor phone cables connect the keyboard to the Arduino MIDI controller.

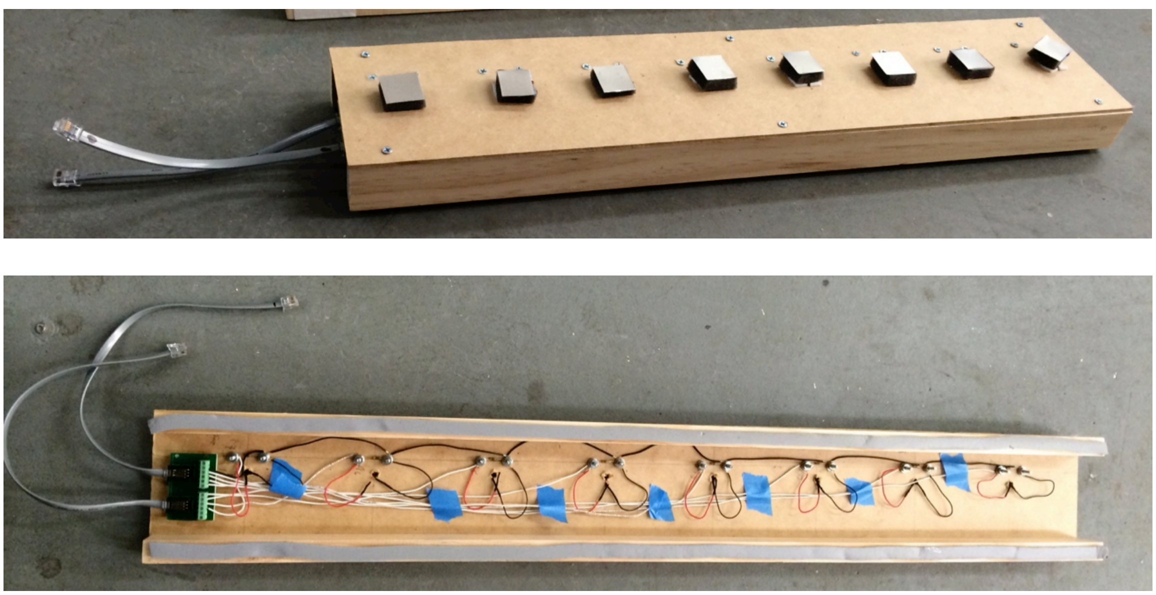

Figure 8: Piezo sensor array used in construction of MIDI enabled xylophone and glockenspiel for third part of Wild Sound. Wooden (xylophone) or metal (glockenspiel) bars are laid on sensors. The bars can either be played acoustically or their vibrations can be picked up by the piezo sensors and converted to synthesized tones.

Relation of Design Thinking to Wild Sound

Although the Design Thinking approach was not formally adopted for the development of Wild Sound, analysis shows that the participants gravitated naturally towards it. *Empathy*—understanding the user's point of view—was evident throughout the development process, although interestingly, not in the manner in which it is usually presented in the theory. Both the composer Kotche and the Third Coast Percussion performers clearly stated that they at best only weakly consider audience expectations in creating their art; there was no consideration interviewing audience members or otherwise field-testing design concepts early in the process. On the other hand, both the composer and performers were strongly committed to ensuring that audience members would have an engaging experience with a Wild Sound performance once the artistic concept was defined. This was evident in many ways, most notably in the hiring of a stage director late in the process to help refine the experience for the audience. As on of the Third Coast Percussion performers said in his interview,

> *"But there was this whole facet of the piece that we were going to be uncomfortable with, and we realized that people would be watching it. So thinking about that outer world, the view of the audience, led us to one of the most important decisions we made in the whole project, which was hiring our stage director. She was so valuable because she was providing that outer perspective on the project, but she was able to go back and forth between the inside and the outside of the project. Because she was not performing, she wasn't part of the original exploration of ideas, and she wasn't building the instruments, she was able to just watch us work and facilitate that, and then watch us perform sections of the piece, and give us an outsider's feedback, and the longer that she worked, the more that she was able to understand how we worked, how Glenn worked, and then come inside and be able to help us translate our desires to a reality that could actually be presented to an audience."*

Another aspect of empathy that has not been discussed in the common expositions of Design Thinking is empathy among participants in a multidisciplinary design project such as Wild Sound. As described in the discussion of environmental constraints above, a key feature of Wild Sound and other multidisciplinary projects is that the *members of the design team are also each other's users*. There was indeed extensive discussion with and observation among the internal user base very early in the process, before even the textual draft of Wild Sound was written and long before any musical notes were committed to a staff. These discussions touched not only on high level ideas for the piece and the basic feasibility of building instruments onstage, but also considered whether such a project would be interesting and engaging for the student engineers. For example, one of the performers shared these thoughts during his interview:

> *The composer/performer relationship can be on a spectrum: it can be very non-collaborative where we ask a composer to write a piece and then it just shows up in the mail all written down, the performers learn it, and maybe the composer and performers only meet at the premier. On the opposite end of the spectrum is the way it was with Wild Sound. Because Glenn as a composer wanted to make sounds on stage that he had never made before, and because he himself is a percussionist, he needed the four of us to be trying things out. There was this long workshopping process, and it made for what I think is the coolest thing about Wild Sound, this really collaborative process, with the ideas coming from Glenn,*

and the music coming from Glenn, and all that music filtered through us as performers, and through… the students as engineers, to realize, in the real world, these abstract ideas into the real world as a live performance.

The empathy that was carefully built between team members proved to be a key ingredient to the overall success of the project.

Following an initial meeting with the performers, and before the final score was completed, the students entered a period of *ideation*, which was strongly encouraged by both the performers and the composer. At this stage in the design process, the students formulated a list of possible electronic instruments exhibiting a variety of sounds and control mechanisms that *could* be used in sections of the piece. Many of these ideas were fanciful or whimsical, yet others formed the basis for unusual instruments that would be part of the final performance.

Prototyping and testing followed ideation. Both the opening and closing scenes for Wild Sound changed very substantially as a result of trial performances with the participants and stage director. Within the engineering team, many prototypes of instruments were developed by the students and tested with the performers prior to the completion of the score. Based on these tests, some instrument concepts were advanced while others were discarded, based on playability, sound, and consistency with the artistic vision and stage performance. Figure 9 shows an early prototype of the acrylic keyboard, fabricated on pegboard. Some of the discarded ideas included instruments that involved drawing with conductive ink, use of temperature, light, and other continuously varying sensors to modulate pitch or timbre of notes, and the use of a Microsoft Kinect system to track performer movements.

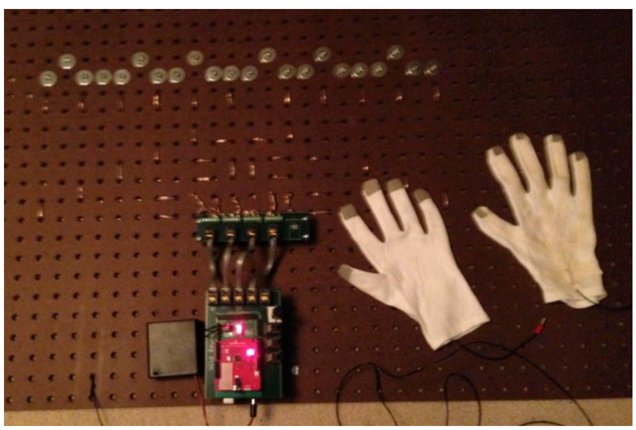

Figure 9: Early prototype of keyboard for part four of Wild Sound.

Participant and Audience Perceptions

The composer, the performers, and the student engineers were asked to describe what they learned from participation in the making of Wild Sound. In addition, the students were asked their views on whether more educational opportunities should be made available that integrate engineering and the arts. Excerpts from responses are summarized below.

Participant Reactions
There were several common themes that emerged from the participants' descriptions of what they had learned. For example, almost all of the participants reported learning something about themselves during the experience. In particular, several participants indicated that they gained some new understanding about their personal workstyles or preferences as part of the project. As Glenn Kotche said,

> *I learned things about myself, that I enjoy working with a team. This is the first composition where I had a director, a lighting designer, where the players had that much input into how the piece would develop, and it's the first time that I worked with engineers, obviously, with people to help facilitate some of my ideas… that was a really good lesson for me, that I should work that way more in the future, and also just knowing that the cross-disciplinary collaboration is something I dig—I didn't know that either. Now I know I like it.*

Additionally, the students reported learning a range of relevant skills on the project, including programming and prototyping. However, perhaps the most interesting finding in this section is that students also identified learning about the similarities between engineering and the arts – particularly around the design process. Students also suggested that these types of experiences would be very engaging for their undergraduate peers.

Audience Reaction
In addition to interviewing the participants in Wild Sound, an online survey was sent to members of the audience who ordered tickets online. 25 audience members responded, approximately 8% of the total attendance. Survey results are summarized in Table 1.

For the first set of questions that relate to audience interest and enjoyment, responses were generally quite favorable. Responses to the second set of questions on audience expectations varied widely—many did not expect the degree to which technology and audience participation would play a role in the production. The third set of questions, which measured audience interest in music, science and engineering, indicate that while the audience had high interest in music, they also had significant interest in science and to a slightly lesser degree, engineering.

Conclusions
Based on responses from participants and audience members, the making of Wild Sound succeeded in providing a highly engaging experience for the developers and audience alike. The juxtaposition of both artistic and technological challenges effectively broadened the perspectives of both of these groups. For the participants—the composer, the performers, and engineers—the multidisciplinary design experience provided new insights applicable to future projects. In particular, students on the engineering team spoke highly of how their involvement in the development of Wild Sound enhanced their understanding of both engineering and music, and advocated strongly for more educational opportunities that combine engineering and the arts. Many of the students felt that such opportunities should be available early in their academic careers, especially at the first-year level.

Analyzing the process of developing Wild Sound using both Herbert Simon's theory of design presented in the *Sciences of the Artificial*, as well as current theories of Design Thinking helped significantly in making sense of the highly complex and interdependent design process. In particular, applying Simon's theories of the "environment as mold" for a design led to the discovery of "non-obvious" artifacts that were invented during the design process, namely a timeline management scheme and a system of MIDI tone patches that greatly improved the overall organization and ultimately success of the project. Having realized in hindsight that these critical components of the design were artifacts in their own right leads us to search for such design opportunities early in any design process and also provides a methodology for doing so.

Table 4: Audience reaction to Wild Sound

Question	Response Scale	Mean	Standard Deviation
How interesting was the event for you?	1: I didn't find it interesting at all 2: I wasn't really interested 3: I was interested 4: I was so interested I'd encourage others to come	3.60	0.71
How enjoyable was the event for you?	1: I didn't find it enjoyable at all 2: I didn't really enjoy it 3: It was enjoyable 4: It was so enjoyable I'd encourage others to come	3.52	0.72
How did the following aspects of Wild Sound or WAVES align with your expectations for the experience?			
Hearing a musical performance	1: I was fully expecting to experience this 2: I thought I might experience this 3: I neither expected this nor was surprised 4: I was a bit surprised 5: I was completely surprised	1.68	1.23
Participating in a musical performance as an audience member		2.96	1.37
Exploring the science and engineering associated with percussion music		2.68	1.45
Learning more about the artistic processes of percussion artists		2.76	1.28
How would you rate your interest in music?	1: no interest at all 7: extreme interest	6.20	0.98
How would you rate your interest in science?		5.20	1.60
How would you rate your interest in engineering?		4.88	1.71

Studying the Wild Sound development process through the lens of Design Thinking provided new insights to extending that theory to multidisciplinary design in general. Specifically, because in a multidisciplinary design team designers are also users of other designers' artifacts, team members must be considered during the critical "empathy" stage. The Wild Sound team came to this conclusion naturally, which contributed greatly to the success of the project. Further, all of the participants in the making of Wild Sound discovered that they *enjoyed* collaborating with experts from other disciplines as part of a team, something that they may not have known about themselves beforehand.

Finally, returning to Simon's theories in *Sciences of the Artificial*, one might speculate as to whether the questions addressed by Wild Sound are in the domain of either natural or artificial science. According to Simon, the natural sciences address questions of "what is," while the artificial sciences address questions about how things "should be" to serve human-centered goals. The making of Wild Sound certainly embodied a lot of artificial science in the design of a new type of musical/theatrical performance and novel musical instruments. On the other hand, the development process frequently incorporated classical forms of scientific investigation, such as in the experimental design, execution, and data analysis of the time studies for constructing instruments. Further, composer Glenn Kotche's primary goal was to answer a very scientific series of "what is" questions: what is noise vs. music, what is musical performance vs. theater. But to answer these questions, he had to design an instrument—in this case the complete composition and performance of Wild Sound—to obtain his answers. In the end, we conclude that the natural and artificial sciences are two inseparable sides of the same coin, each needing the other to make progress.

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