

The Electric Guitar Project:

Leveraging a Cultural Icon to Build a STEM Identity

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Introduction

Engineering has solved many of the world's most pressing challenges, yet it continues to grapple with a fundamental internal issue: the lack of diversity within the profession—a gap that limits its ability to serve all of society effectively. According to the NCSSES, in 2019 only 4% of working engineers were Black or African American, and only 16% were female (National Center for Science and Engineering Statistics, 2019). To ensure universal design approaches and solutions to modern problems that serve everyone, engineering design fields must employ demographics that represent our diverse societies. Laying the foundation for careers in engineering and technology requires engagement with STEM fields at an early age. Doing so through music creates engagement opportunities for everyone.

The electric guitar is a musical instrument and tool for self-expression. Like most tools, it has primarily been wielded by cisgender white men since its invention in the early 1930s (Bayton, 1997; Martin, 2024). Mavis Bayton (1997) stated that “rock is associated with technology, which is itself strongly categorized as ‘masculine’” (p. 42). Technolo-

gy cannot be separated from the culture in which it was created, but it has the potential to evolve alongside cultural changes. While much has changed in the nearly 30 years since Bayton expressed that thought, the persistent gender gap in engineering and technology fields would suggest that these beliefs are still intact. Musical instruments have gender appropriateness associations (Wych, 2012; Persson, 2017; Harrison & O'Neill, 2000), as has engineering historically. Perhaps lessons from either culture can inform the other. Engineering has evolved in regard to gender, but not without successes and failures at increasing interest and recruitment, similar to music. Much like the toy industry's attempt to cater to girls with pink engineering toys in the early 2000s, guitar manufacturers (Daisy Rock, Gibson, Fender, Luna) tried to encourage girls by manufacturing “girl guitars” in the 1990s (Crespo, 2010). This was in part due to physical size and design of smaller guitars decreasing in manufacturing as natural weeding out factors during the 1800s (Crespo, 2010), which coincided with the decline in women guitar players. During this resurgence period, girl guitars had modifications in weight,

body contour, electronics, thickness and width of neck, and of course, style and color. Marketing, third wave feminism, and pop culture played roles in this small movement, but the socialization and challenge of masculine ideologies linger, sales did not meet expectations, and guitars became standardized (Crespo, 2010). Even still, guitar players modified for improvement toward electricity and power (Bourdage, 2007) and continue to customize their instruments. This is where tinkering, designing, and creativity around an electric guitar can generate opportunities for students who are artists or musicians to engage in STEM and build STEM identity.

This custom electric guitar project was designed as a one-week summer camp experience for Grade 8-12 girls and gender-expansive students to explore the artistic design, making, and technical aspects of the solid body electric guitar. The electric guitar serves as a platform for learning a variety of physics concepts, including mechanical vibration and the impacts of string length, tension, and diameter on frequency. The electrical aspect of the guitar presents an introduction to electricity, electromagnets, and the



induction of electricity in a circuit from a changing magnetic field. The controls circuit offers an opportunity to introduce the concepts of voltage, resistance, impedance, and circuit elements, including potentiometers and capacitors.

Students start with cardboard templates where they sketch their designs for the body of the guitar. They then digitize that template through a 3D modeling software, refining the design and creating tool paths for the CNC router to cut out the body. Students use traditional woodworking tools like sanders, bandsaws, and drill presses as they build their guitars. Finally, students learn how to solder the circuits. The guitar jack is connected to an oscilloscope to demonstrate the function of the pickups and create a visualization of the transduction of mechanical energy to electrical energy. Through testing and trouble-

shooting, students learn the iterative nature of engineering design. By the end of the week, students leave with a functional guitar reflecting their unique identity.

Eccles and Wigfield's (2020) situated expectancy-value theory (SEVT) states that student beliefs about whether or not they can do something are related to how much they value what they are doing and can ultimately influence choices made to pursue a specific task or discipline. According to Eccles and Wigfield (2020), value takes multiple forms: intrinsic, attainment, utility, and cost. The custom electric guitar project demonstrates the utility value of technology like 3D modeling and digital fabrication, along with engineering and physics principles of electric circuits and the electromagnets found in pickups. According to SEVT, students' motivation to pursue additional STEM learning

can increase by providing a socially supported and highly scaffolded project-based STEM experience with high perceived value.

The Custom Electric Guitar Project

THE DESIGN PROCESS

The custom electric guitar project begins with a discussion of the anatomy of an electric guitar and a guitar "petting zoo" where students hold guitars with various weights, centers of gravity, and shapes. This gives the students an idea of what works for their bodies and potential playing style and what does not. At this point, students begin to formulate ideas for what their guitar body will look and feel like and in some cases iterate on designs they envisioned prior to the petting zoo. Ergonomics and the principles of design are discussed. Through this process students engage with benchmark STEL-1M, Grades 6-8. In the case of the guitar, they are iterating the shape of the body and location of the controls to make the guitar fit their physical preference and playing style.

The students are given a cardboard template that provides constraints and expectations for the size of the body and the critical components. Once the preliminary designs are complete, the students are provided with a digital template and an introduction to 3D modeling. Students then take a picture of the cardboard design and import it into Fusion 360 as a canvas to be traced (Figure 1).

2D TO 3D MODELING

In the next step, students develop a full 3D model of the guitar body and pickguard (Figure 2). Through this process, students learn the value of 3D modeling and how it allows for visualizing and iterating the designs. They also learn the workflow from the 3D model to the CNC router and waterjet. This is one of the most difficult steps for the students, as

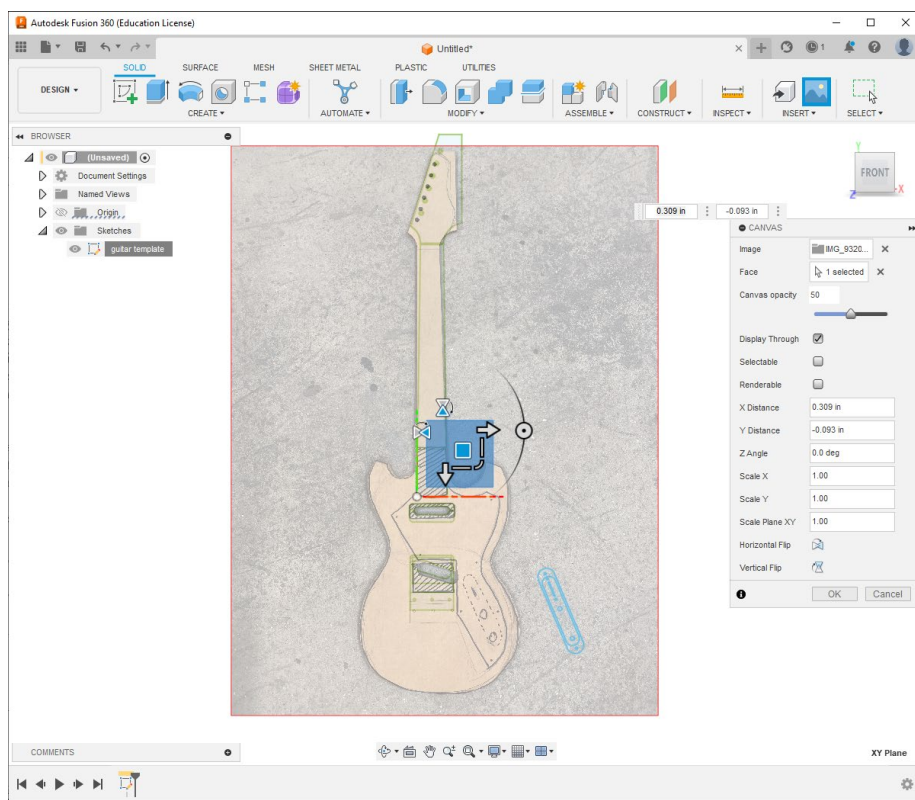


Figure 1. A digital template is provided to students to ensure the distance between the neck pocket and bridge pocket is maintained to match the 25.5" scale.

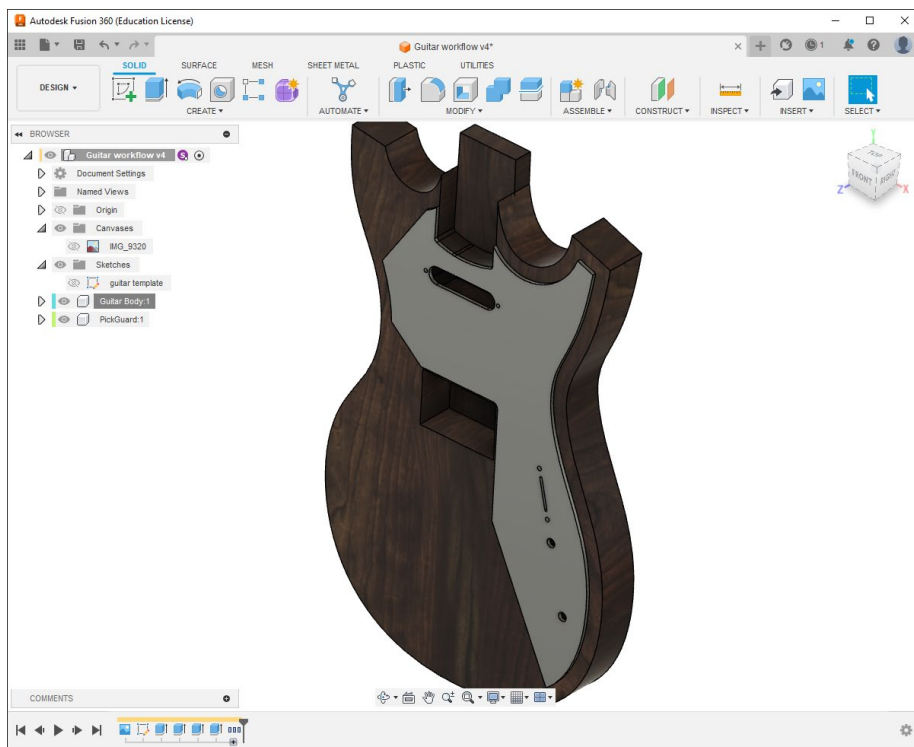


Figure 2. A finished model of a guitar body and pickguard using Fusion 360.

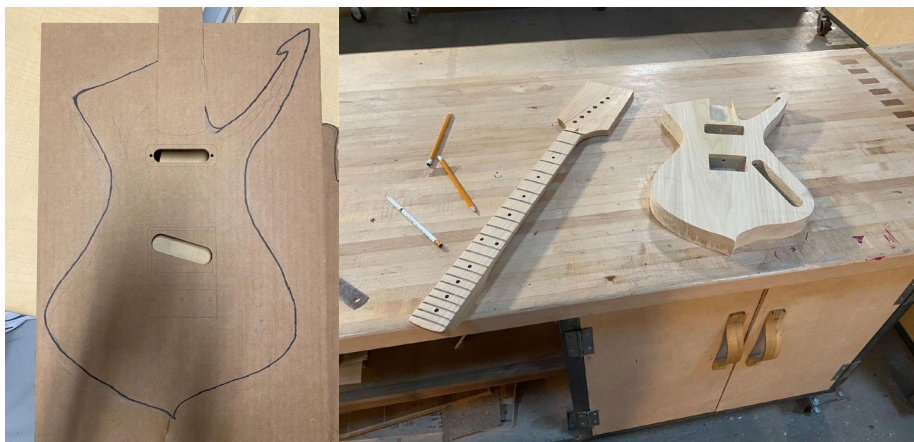


Figure 3. Cardboard template with sketch (left), and guitar body and neck (right).

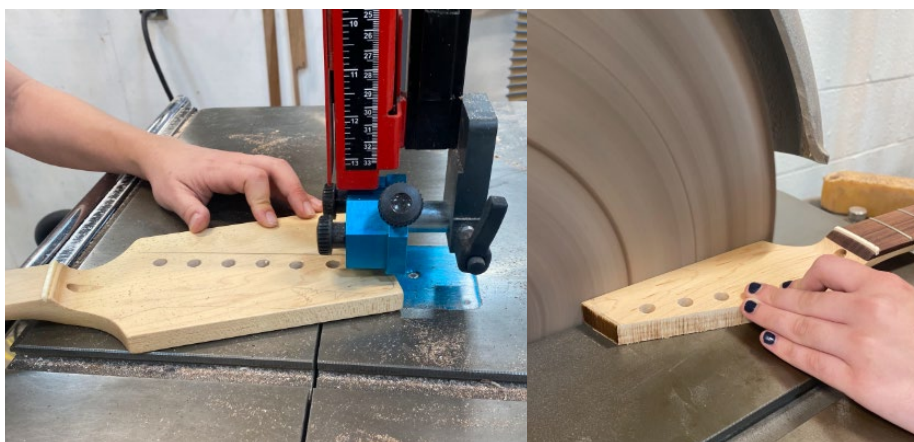


Figure 4. The headstock is custom-cut on the band saw and then sanded.

most have never used 3D-modeling software before. However, this step teaches students the difference between raster and vector graphics, creating an opportunity for them to understand the real-world value of algebra through computer graphics and CNC toolpaths.

DIGITAL TO PHYSICAL

Once the model is complete and tool paths for the CNC router have been created, the bodies can be cut out. For the sake of time in the constrained one-week format, blanks of dimensioned lumber and manufactured paddle head guitar necks are provided for the students (Figure 3). Poplar wood is used because it is relatively lightweight and among the more affordable hardwoods. The material process from tree to rough-sawn lumber to dried dimensioned lumber is discussed.

Students participate in the setup of the CNC router and fixturing of the blank. Once the body is cut, the students use sanders, rasps, and files to shape the bodies to their desired aesthetic. Before painting, holes are drilled for the jack and wire routing. This engages students in the use of a hand drill and drill press and exposes them to various types of drill bits supporting Technology and Engineering Practice TEP-3: Making and Doing.

THE HEADSTOCK AND PICKGUARD

The necks are purchased with a blank paddle head so students can drill the holes for the tuning machines and shape the headstock as desired. The pickguards are cut from 16 gauge aluminum on a water jet to further engage students in digital fabrication methods and material literacy. These steps allow the students to use more tools, like the die grinder and files to further engage TEP-3: Making and Doing.

ASSEMBLY

Once the guitar bodies are painted, the pickguards are cut out, and the headstocks are drilled and shaped,

$$f = \frac{v}{\lambda}$$

$$\lambda = 2L$$

$$v = \sqrt{\frac{T}{m/L}}$$

$$f = \frac{\sqrt{\frac{T}{m/L}}}{2L} \Rightarrow f \text{ INCREASES (HIGHER SOUND) IF THE TENSION INCREASES, THE MASS INCREASES, OR THE STRING LENGTH DECREASES}$$

v = VELOCITY OF THE STRING, λ = WAVE LENGTH
 L = STRING LENGTH
 T = TENSION OF THE STRING
 m/L = LINEAR DENSITY OR THE MASS OF THE STRING/UNIT LENGTH

Figure 5. A screenshot of the discussion on the effects of string length, mass, and tension on frequency.

and the guitars can be assembled (Figure 4).

The neck is bolted onto the body, and the pickups and controls are assembled in the pickguard and bridge assembly. During this phase students learn about the function of the pickups through a demonstration of the transduction of mechanical energy to electrical energy using an oscilloscope. The induction of

electric current in a coil of wire by a changing magnetic field (Faraday's Law) is demonstrated, connecting with the MS-PS3-5 and HS-PS3-3 energy standards. This also includes a discussion on why electric guitar and acoustic guitar strings are not necessarily interchangeable, since the electric guitar strings must be ferrous to disrupt the magnetic field of the magnets in the pickups. With

the oscilloscope demonstration, string vibration and frequency are discussed. Students are shown the different frequencies that correspond with the different strings of the guitar when in standard tuning. The students observe through the oscilloscope that although the strings have the same length, the thicker strings have a lower frequency than the thinner strings. From

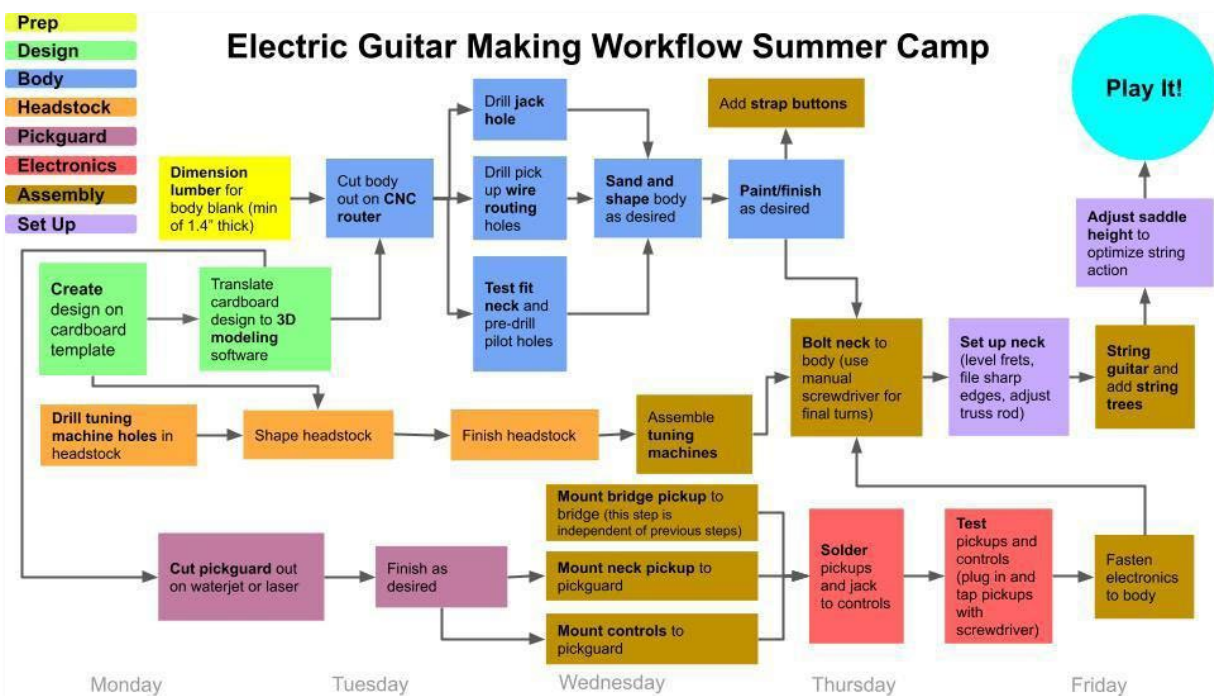


Figure 6. Guitar project summer camp flow chart.

GUITAR CURRICULUM CONNECTION TO STANDARDS (NGSS AND STEL)	
4-PS3-2 Energy	Grade: 3-5, 4
Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.	
4-PS3-4 Energy	Grade: 3-5, 4
Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.*	
HS-PS2-5 Motion and Stability: Forces and Interactions	Grade: High School (9-12)
Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.	
MS-PS3-5 Energy	Grade: Middle School (6-8)
Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.	
HS-PS3-3 Energy	Grade: High School (9-12)
Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*	
MS-PS4-1 Waves and their Applications in Technologies for Information Transfer	Grade: Middle School (6-8)
Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.	
HS-PS4-1 Waves and their Applications in Technologies for Information Transfer	Grade: High School (9-12)
Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	
STEL-1M: Nature and Characteristics of Technology and Engineering	Grade: Middle School (6-8)
Apply creative problem-solving strategies to the improvement of existing devices or processes or the development of new approaches	
TEP-3: Making and Doing	Grade: Middle School (6-8)
Exhibits safe and effective ways of producing technological products, systems, and processes.	
TEP-3: Making and Doing	Grade: High School (9-12)
Demonstrates the ability to regulate and improve making and doing skills.	

Table 1. Standards Summary Table for the Guitar Project from elementary to high school.

this, the relationship between mass and velocity can be introduced, observing that the thicker strings vibrate more slowly and therefore have a lower frequency which correlates to a deeper sound. This is demonstrated through the equations for frequency (Figure 5).

Students learn to solder and follow a wiring diagram to complete the guitar circuits, testing the circuit before fully assembling the guitar. Testing is done by plugging the jack into an amplifier and lightly tapping the pickups with a screwdriver or other ferrous tool further demonstrating

COMPONENT CHECK LIST	
Control Assembly	
Bridge	
Tuning Machines	
Strap Buttons	
Bridge Pick-up	
Neck Pick-up	
Jack	
Jack Plate	
Strings	
String Trees	
Neck Plate/Screws	
13"x22"x1.4" Wood Blank	
13"x22"x16ga Aluminum	

Table 2. List of components for guitars.

Faraday's law. Once the circuit is complete and functional, the pick-guard and bridge can be mounted, and the guitar can be strung. When this process is completed, students tune their guitars and play them!

Content Opportunities

Depending on how teachers want to engage their students and the grade level of the students, there are a variety of opportunities to introduce physics related to sound and electrical and materials engineering. Stringed instruments can show relationships between properties such as frequency, sound waves (longitudinal and transverse standing), resonance, pitch, mass, length, and tension (Tagg, 2013). From an electrical engineering perspective, the electric guitar teaches circuits, sensors and inputs, voltage, current, and power. From the materials engineering perspective, stringed instruments provide opportunities to study stress, strain, tensile strength, Young's modulus, elastic constant, and density (Kitto, 2007). The particular physics

of string-bending, whammy-bar, fretting force, and vibrato relative to the electric guitar can also be taught (Grimes, 2014). All of this can lead to discussion of the evolution of the electric guitar from single coil pick-ups to advancements like automated tuners (Gough, 2010) and ideation of how electric stringed instruments can be further designed or engineered.

Lessons Learned

This camp has had five years of history and evolution. Each year, lessons are learned, and the consistent feedback is that the camp should be longer. Building a fully functional electric guitar in one week is tough, but doable. Stretching it out over two weeks would give more room for exploration and a deeper understanding of the concepts.

Over the five years, there have been three cisgender male participants out of 37 total participants. Instructors have observed them approaching the project with more confidence than their female and gender-expansive counterparts. They have also tended to have more previous experience with 3D modeling than their counterparts. On average, the campers report disliking the 3D modeling but loving the painting.

Conclusion

The custom electric guitar summer camp is very challenging for both the students and the camp staff. Despite the challenges, it is also incredibly rewarding. The project's intrinsic value is clear when students hold their completed guitar for the first time. The camp has great potential for research, so next steps include collecting data on student experiences and perceptions.

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