Describe the problem your project is attempting to solve

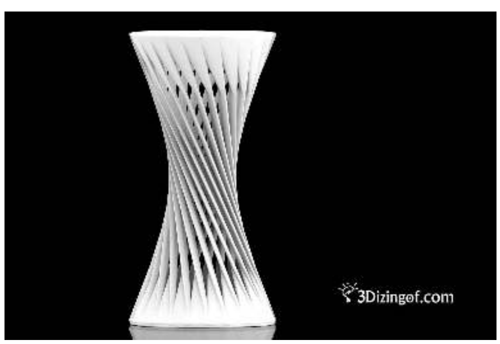
The eventual goal of this project was to submit a printed vase to the Santa Fe Home Show, which would showcase the potential of 3D printed designs for interior decoration. The primary problem was therefore one of creating something aesthetically pleasing. The two primary requirements were that the vase was **aesthetically pleasing** and that it was **representative of 3D printed design**.

Describe how you project addresses this problem

The elegant unbroken curves of the Klein bottle fulfill the first requirement of the design.The Klein bottle also represents a complex geometry, which is a domain that 3D printed is especially well suited for. Although it would not be impossible to realize this design through another method (for instance by sculpting it in clay, by hand), using FDM to manufacture the design requires little work beyond the CAD stage, and the model can be easily reproduced, with high fidelity, as many times as is desired. For this reason, it is also representative of the 3D printing, and therefore fulfills the second requirement discussed above.

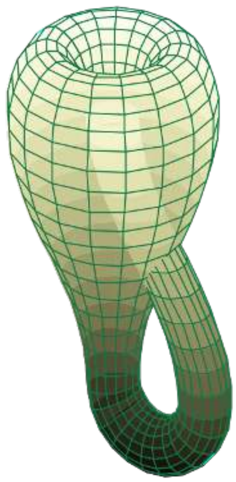
Describe your process for developing this design

Before beginning to model the part, I researched what other 3D printed vases other people had designed. Many of them were comprised of elegant mathematical curves, so I chose to go with a stylistically similar design.

Sample vase designs from DuckDuckGo image search

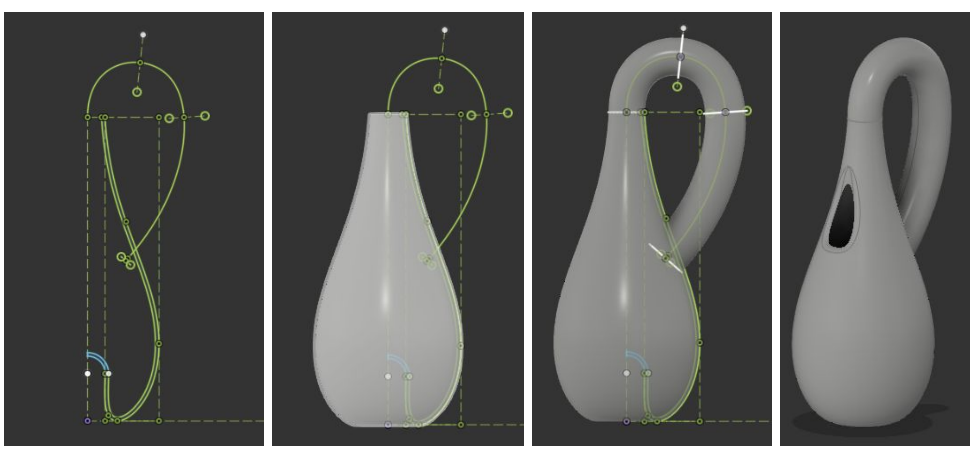
Eventually, I settled on a design based on the Klein bottle, a specific type of mathematical surface.



Representation of the Klein bottle

Because the design would be composed entirely of spline curves, which are difficult to constrain, I began by creating a rigidly defined bounding box onto which I could anchor the splines, and which allowed me to more easily control the dimensions of the model.

To make the design easier to model, I split the design into two pieces: a bulbous, rotationally symmetric base, and a tube-shaped neck. I created the basic form of the base by revolving a spline around a central axis, and I created the neck by sweeping a circle along another spline that defined its curve.



Visualization of design process

Did you encounter any unanticipated problems with this approach? How did you solve these problems?

Initially, I intended to create a single, figure-eight-shaped spline that would serve as the skeleton of the entire model, but this proved difficult to reason about and conceptualize, in part because of the physical impossibility of the true Klein bottle. My eventual solution was to split the design into two pieces: a base and a neck. This had the additional advantage that it allowed me to take advantage of the symmetry of the bulbous base, which greatly decreased the complexity of the model and made my workflow significantly easier.

What did you learn in completing this project?

There were a number of lessons I learned through my work on this project. The first of these was that decomposing a model into separate parts–in this case the base and the neck–and focusing on designing those parts separately can make the design process more manageable than considering the entire design at once. This is an approach that I sometimes think of as **modular design**.

Second, I learned that reducing the number of steps required to build the model can result in a more elegant and effective design. In this case, the model is primarily composed of only three operations: a *revolution* of a curve around an axis, a *sweep* of a circle along a second curve, and a *join* operation to combine the two bodies. To put this lesson succinctly, **less is more**.

The final takeaway from this project is that **taking advantage of symmetry** can vastly reduce the amount of work required to complete a design. In this case, the base of the model has rotational symmetry, which allowed me to define the entire geometry by a single curve and an axis. The neck of the bottle, too, has a sort of translational symmetry, in that taking a cross section at any point along the neck of the bottle produces a circle with the same diameter, which again makes defining the geometry simple: it is entirely defined by the sweep path and the diameter of the circle.