COMMUNICATION

Utilizing ChatGPT to Assist CAD Design for Microfluidic Devices

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ChatGPT is a generative AI model that has garnered tremendous public interest due to its ability to solve diverse problems through high-level reasoning and analysis. Among its features is an ability to create and debug code. While this capability has been explored with conventional programming languages such as Python, it has yet to be applied to computer-aided design (CAD). In this work, we utilized GPT-4 to create functional microfluidic components using OpenSCAD, an open-source CAD software package. Through an iterative dialogue, GPT-4 created functional designs for a helix/spiral, a valve, a t-junction, and a serpentine channel. This concept could facilitate CAD in the future for both technical and non-technical users and can be reasonably extended to other fields.

Introduction

A functional prototype of ChatGPT, an artificial intelligence (AI) chatbot, was released in November 2022 by OpenAI, and it received immediate public attention. Given its widespread capabilities, ChatGPT and other generative AI systems have been the subject of fervent public discussion, both for their beneficial but also potentially harmful implications[1]. Among the many interesting characteristics of ChatGPT is the ability to write and debug code[2,3]. While these capabilities have begun to be explored for several programming languages, there has yet to be an application of ChatGPT to computer-aided design (CAD).

In recent years, the use of 3D printing technology for the fabrication of microfluidic devices has burgeoned[4,5]. Among its benefits are (1) rapid prototyping, (2) automatic, one-step fabrication of devices, and (3) true three-dimensionality that allows for high degrees of complexity. In order to fabricate devices with 3D printing, it is first necessary to build a model using CAD software. Many CAD users rely on GUI-based programs such as Solidworks, Fusion 360, or OnShape to construct models, but there are scripting solutions to CAD such as OpenSCAD, an open-source programming language. In OpenSCAD, users generate models by performing Boolean operations and other manipulations on geometric primitives (such as cubes, spheres, and cylinders).

Given the open-source nature of the language, we were interested in the potential of ChatGPT to assist in the fabrication of CAD models. Here, we demonstrate that with relatively few prompts, ChatGPT is capable of generating functional CAD designs for microfluidic components. In addition, we applied the same methodology to 2D designs towards users for which traditional soft lithography techniques are preferable. While this work is rudimentary, the evolutionary nature of AI models suggests that as the model is trained, more complex structures and combinations thereof could be quickly designed and implemented, potentially leading to a future where users, even inexperienced ones, could simply describe objects they desire and generate an output file capable of being rapidly fabricated with a 3D-printer.

Methods

***Code generation*:** GPT-4 was instructed to generate OpenSCAD code for a target microfluidic component, and then code was compiled in OpenSCAD (v2021.01). For the 2D SVG, GPT-4 was asked to generate code that outputs an SVG image. The code output and an image of the compiled result were subsequently recorded and evaluated for accuracy. Issues found in the code/structure were brought to the attention of GPT-4 to guide the subsequent attempt. No code was modified by the authors. The code can be readily accessed using the following link: https://github.com/bgoenner/ChatGPT_Microfluidics/.

***Device fabrication for 3D designs*:** Upon receiving a satisfactory model, an .stl file was outputted using OpenSCAD and imported into Chitubox, a slicing program for use with mSLA 3D printers. Devices were printed using a commercially available mSLA 3D printer (Sonic Mini 8K, Phrozen) at 405 nm using a transparent resin (Ortho Flex, NextDent). A rectangular slab of glass was permanently affixed to the building plate of the printer with a

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clear, double-sided adhesive to improve surface smoothness and optical clarity of devices. After printing, devices were immersed in two ethanol baths for 3 minutes each, and residual resin was pulled out of the channels using a vacuum source. Devices were allowed to dry for 10 minutes before being placed in a Form Cure (Formlabs) chamber and exposed to 405 nm UV light at 60 °C for 30 minutes.

Results and discussion

We conducted a dialogue with GPT-4 towards the goal of creating four common microfluidic components: a helix/spiral (**Figure 1**), a valve (**Figure 2**), a t-junction (**Figure 3**), and a serpentine channel (**Figure 4**). Our approach was to request the structure and then enter into a back-and-forth dialogue in which the code and resulting structure were evaluated for errors and fed back into GPT-4. No code was altered at any point, as the intention was to confirm that even small errors could be identified and fixed. Through this process, GPT-4 demonstrated an exceptional ability to present unique solutions to the construction of these components as well as debug erroneous code. In addition, GPT-4 annotated the code in helpful ways and explained its function in the dialogue.

All structures were created successfully by GPT-4 in less than 14 prompts and capable of fluid flow. GPT-4 answers were immediate, and as a result, the only time expenditure involved was compiling the code in OpenSCAD, which ranged from 1 second to a few minutes depending on the mesh size and number of shapes. Overall, the total time to generate each structure from start to finish was under 1 hour. For each structure (excluding the T-junction), and depending on skill level, this may actually be comparable in time to a normal CAD process, but for sufficiently advanced structures, a normal CAD process is likely more preferable at this stage. However, as artificial intelligence models rapidly advance, we envision a future in which the use of artificial intelligence may be superior even for advanced CAD users creating sophisticated designs. Just as GPT-4 is used to create drafts of written documents, an advanced user could deploy GPT-4 to create an initial approximation and make adjustments as needed. We expect that with additional training, only a few prompts would be required to generate these same structures, which could allow users to focus more on assemblies and combinations of components. Furthermore, designs could also be paired with robust technical discussion of proper design principles and field-specific knowledge.

While the primary focus of this work was the design of structures that can be 3D-printed, it should be noted that 2D designs that would be more appropriate for conventional soft lithography are also possible. As an example, we utilized GPT-4 to create an SVG file of a serpentine channel as well as an OpenSCAD file of a spiral pattern, which can be exported to DXF, SVG, and PNG file extensions (**Figure 5**). This may be desirable for users that either already have an established workflow or do not have the technical knowledge necessary to 3D print microfluidic devices. For some users, this methodology could also be utilized to create 3D printed molds for soft lithography, especially considering the rapid advances in 3D printing resolution, where pixel sizes for common SLA printers are currently in the range of tens of microns.

This methodology may also be extended to other languages. For example, many common CAD software packages such as Solidworks or Fusion 360 have Visual Basic or Python APIs. As such, GPT-4 could be used to either augment or completely create structures for users that would prefer their standard workflow.

The primary limitation of this approach is that a user currently needs to have basic knowledge of the programming language they are utilizing to recognize errors and guide ChatGPT appropriately, which may be inaccessible to a non-technical user. Moreover, it is unclear what the extent of ChatGPT's debugging capabilities will be as structures become more complex. Nevertheless, ChatGPT was able to successfully interpret our commands and create/modify the code appropriately, and like many new methodologies, it is likely that this process will become considerably more powerful and user-friendly with further development. It is conceivable that with rapid advances in artificial intelligence and user-friendly interfaces, very little technical knowledge would be required for operation.

Conclusions

In this work, we demonstrated the design of functional microfluidic devices using ChatGPT. While this concept is in its infancy, one can imagine a future in which CAD is greatly facilitated through the use of generative AI. Researchers in non-engineering fields could design useful structures without the need of advanced training, and technical users could expedite their workflows and rapidly create sophisticated structures. While we applied this concept towards microfluidic components, it could be reasonably extended to other fields as well. As AI models improve through both algorithmic development and user training, there is great potential for an evolution in how CAD is implemented.

Author Contributions

M.D.N conceptualized the work, performed data collection /analysis, and wrote the manuscript. B.L.G performed data collection/analysis and reviewed and edited the manuscript. B.K.G reviewed and edited the manuscript.

Conflicts of interest

There are no conflicts to declare.

Notes and references

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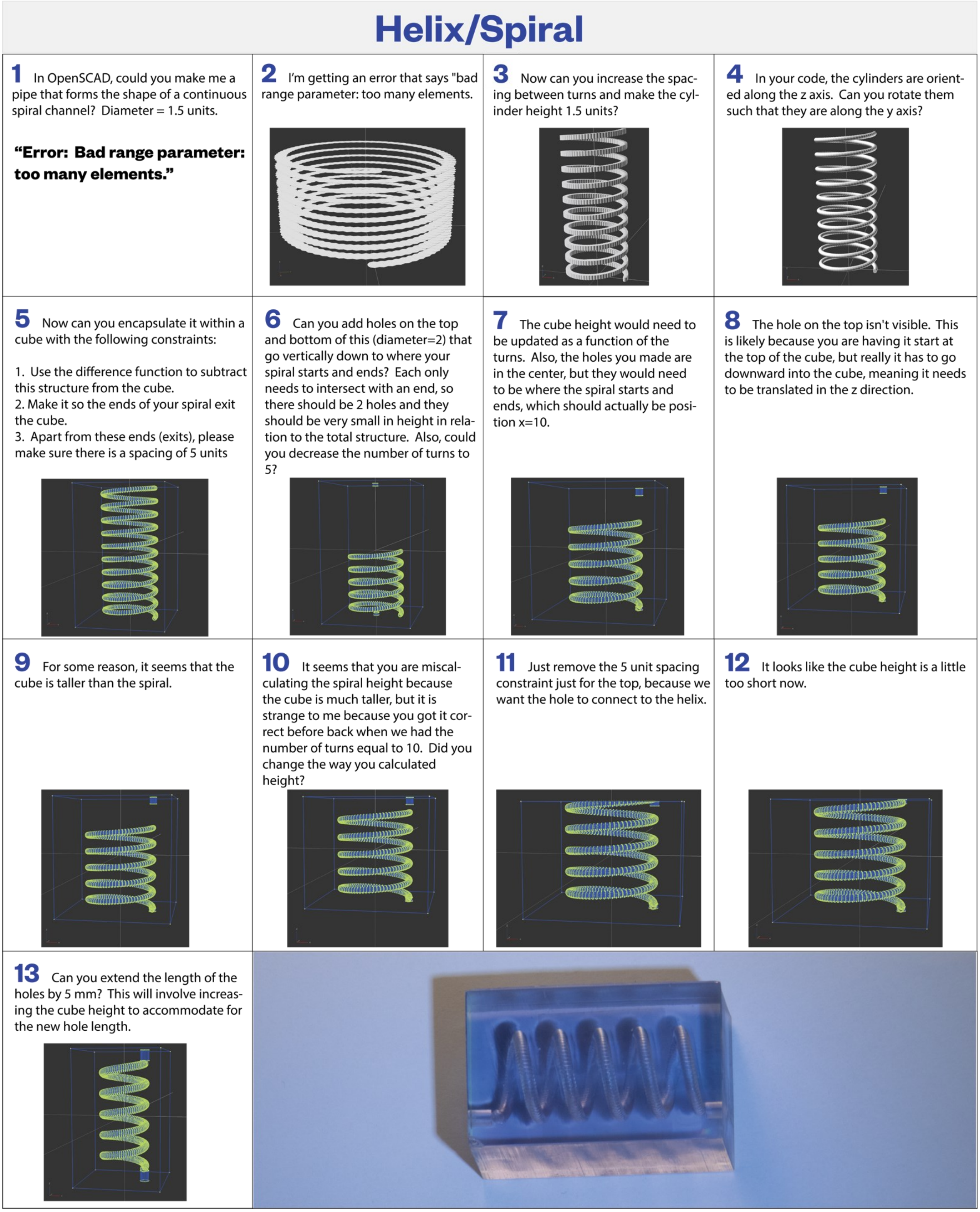
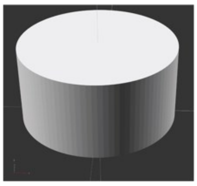


Figure 1. GPT-4 dialogue towards the design of a microfluidic helix/spiral channel.

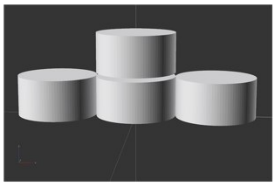
Valve

1 Can you generate OpenSCAD code that creates a microvalve, which will require two cylinders: one for the pneumatic chamber and one for the fluid flow chamber. They are concentric with a 100 micron spacing between the chambers which is the membrane. Two cylinders should be coming out of the bottom of the fluid chamber, offset from the centers, which will be the ports for the valves. The base unit for the OpenSCAD code should be millimeters.

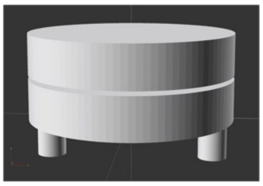


2 The pneumatic chamber and fluid chamber should be the same diameter. The offset of the pneumatic chamber will be the fluid chamber height added with the membrane height.

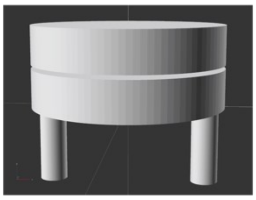
3 Define a new variable "port height" and use this variable as the port offset. Define the port height as 2 mm. Also, define the chamber height as 1 mm and the chamber diameter as 2 mm.



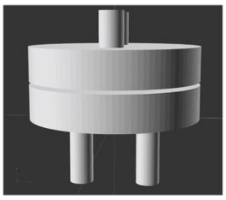
4 The port offset should be a z-offset so they are connected to the bottom of the fluid body. Also change the chamber diameter to 5 mm and port diameter to 0.7 mm.



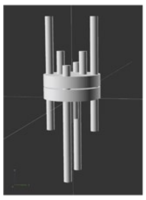
5 Change the port height to port offset of the valve. The x-offset and z-offset of the ports should be the port height.



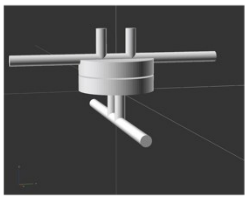
6 Change the port offset to 1 mm and add two ports to the top of the pneumatic chamber. The new ports should use the same offset but in the y-direction instead.



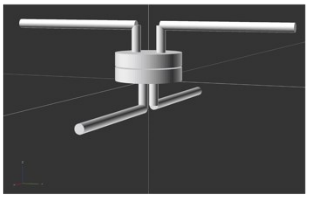
7 The pneumatic port z-offset should be 2 chambers and the membrane. Also, add routing channels to the ends of the ports for all of the ports that lead directly away from the origin.



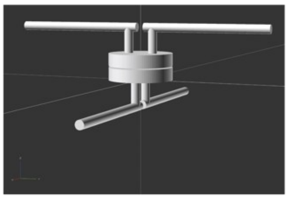
8 Can you rotate the routing channels so that that they are perpendicular to the port channels?



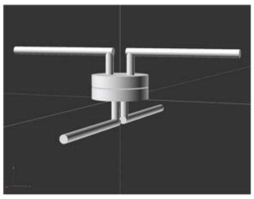
9 The offset of the routing channels should be half of the channel length and the port offset only. Additionally, the pneumatic routing channels should also include the port height in the z offset.



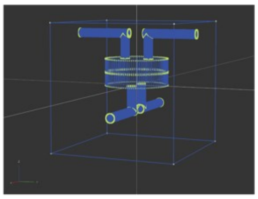
10 Move the routing channels toward the origin by the port diameter so that the routing channel edge and port edge meet.



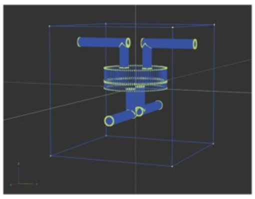
11 Instead of moving the routing channels by the port diameter, move them by port radius.



12 Add a 10 x 10 cube that subtracts all the geometry created thus far. I suggest using a union function for the current created geometry. The cube should be centered at the origin.



13 Can you make the fluid chamber height 500 microns and the pneumatic chamber 1 mm?



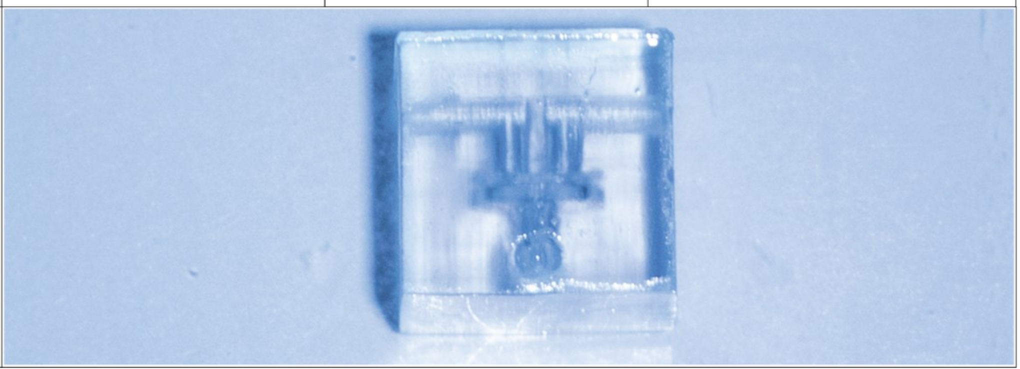


Figure 2. GPT-4 dialogue towards the design of a microfluidic valve.

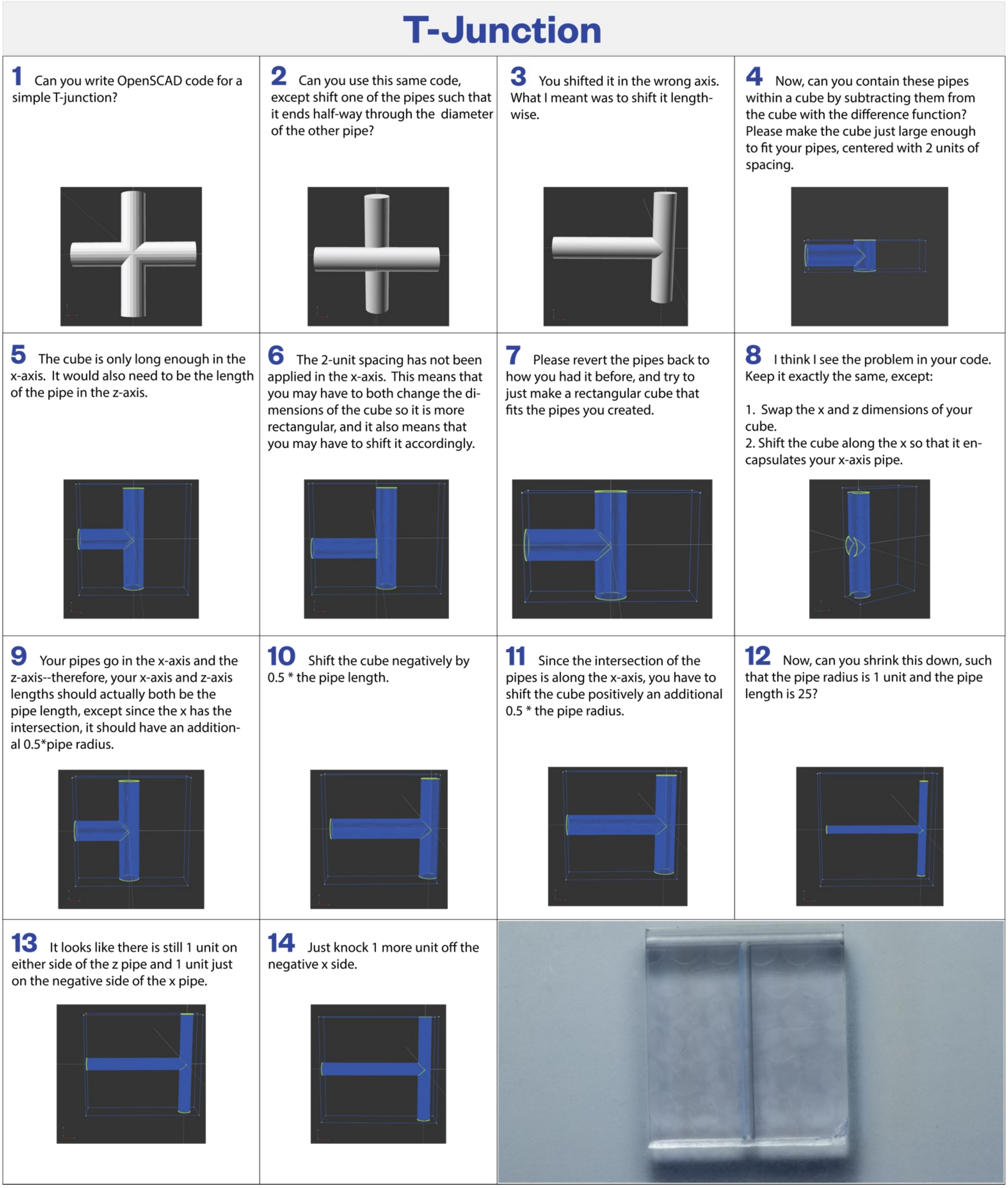


Figure 3. GPT-4 dialogue towards the design of a microfluidic t-junction.

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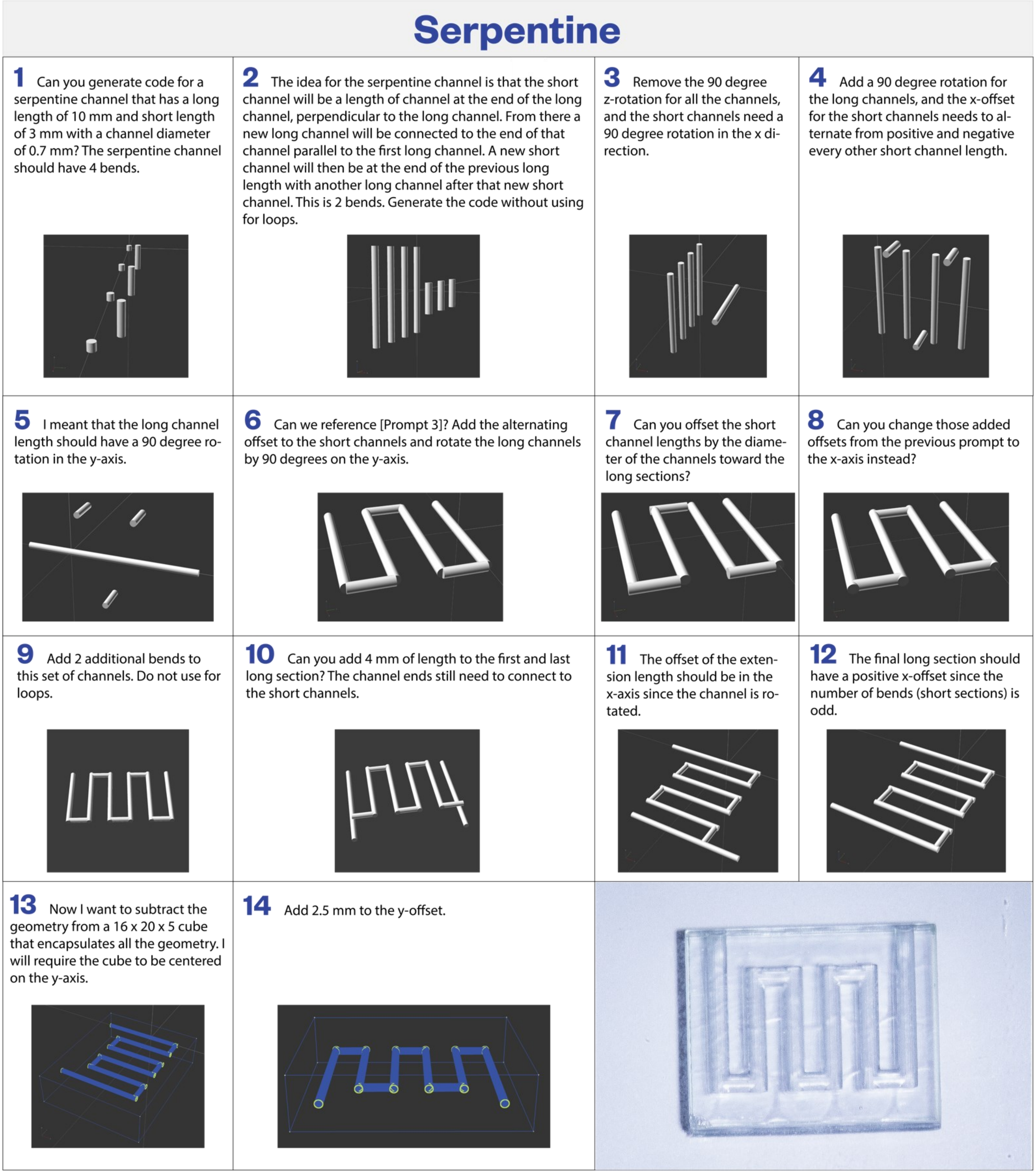

Figure 4. GPT-4 dialogue towards the design of a microfluidic serpentine channel.

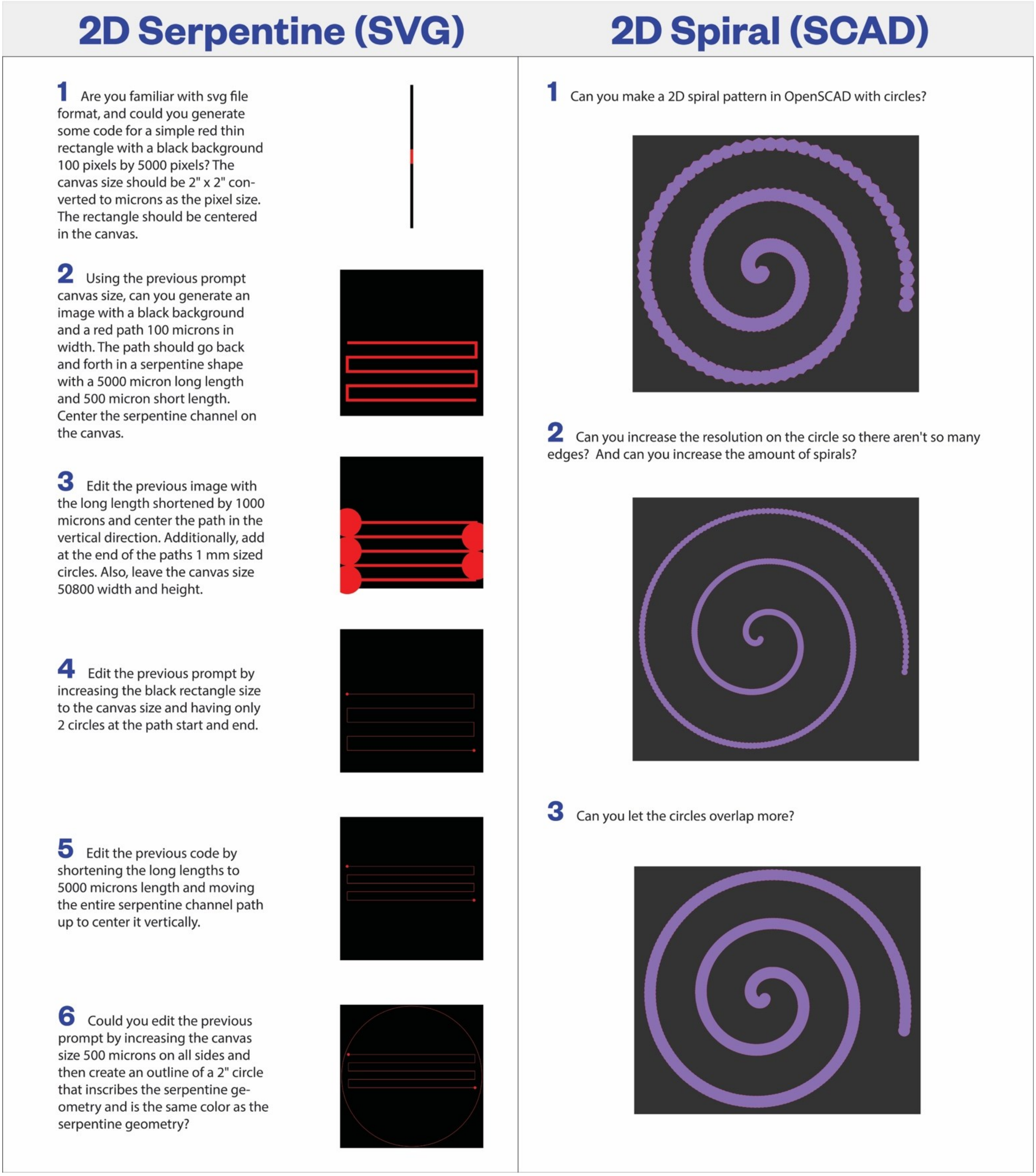

Figure 5. 2D patterns generated by GPT-4. GPT-4 was used to create an SVG of a common serpentine channel (left) and an OpenSCAD file (SCAD) of a spiral, which can be exported to DXF, SVG, and PNG files extensions.