TITLE Cube set

PROJECT Puzzle Cube

Continued from Page

Puzzle cube requirements:

- ~~σ_x~~ - $x_i \in [\mu - \sigma_x$ ~~fuzzy~~ ~~end~~ $\mu + \sigma_x]$, $\mu = .75$
- x_i = cube length ~~from grainy~~ end to ~~fuzzy~~ end
- find problem source for cube size inconsistency
- tolerance = σ_x
- 6 parts; 2/5 parts interlock, 27 cubes
- ~~Cube sizes~~
- 4 to 6 cubes per part
- unique parts
- perfect cube

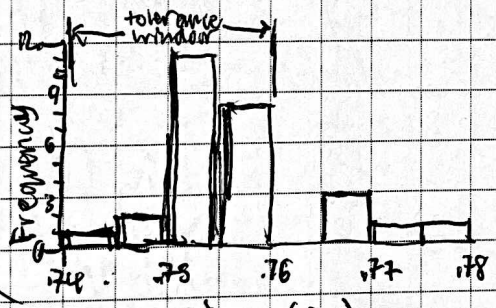
Cube set

#	1	2	3	4	5	6	7	8	9	10	11
size (in)	.750	.767	.766	.756	.745	.756	.753	.750	.755	.787	.762
#	12	13	14	15	16	17	18	19	20	21	22	23
size (in)	.765	.750	.765	.751	.754	.751	.753	.758	.752	.771	.757	.750
#	24	25	26	27								
size (in)	.779	.741	.755	.749								

tolerance window = [.74, .76]

$\sigma_x = \sqrt{\frac{1}{n-1}\sum(x_i - \bar{x})^2} = \sqrt{\frac{1}{26}\sum(.750-.75)^2 + (.767-.75)^2 + \dots} \approx$ ~~0.00~~ 0.010

Cube set # size



reject cubes 2, 12, 14, 21, 24

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TITLE cubes & the algorithm PROJECT Puzzle cubes

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New cubes:

#	2	12	14	21	24
size (in)	.752	.782	.769	.754	.757

reject cubes 12 and 14

Set 3 of new cubes:

#	12	14
size (in)	.742	.758

accept both.

I have two options now:
1) make designs for the pieces myself
2) spend several hours to automate the process, saving several minutes.

Option 2 sounds like a better idea.
Algorithm idea:
1) determine how to divide the cube count for each of the 5 pieces.
2) for each piece:
   2.1) for each cube:
      2.1.1) determine which areas a piece can connect to without overlapping another piece.
      2.1.2) pick one at random
      2.1.3) append the space to the piece
   2.2) update list of available spaces
   2.3) if at any point, there are no spaces, restart.
3) for each piece:
   3.1) check connections/contacts in each direction with each piece for the x, y, and z axes.
   3.2) check that at least 2 pieces contact each other in all 3 axes, and restart if not.

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TITLE The algorithm contd PROJECT Puzzle Cube

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The Algorithm in more detail:

Generating pieces:

Store state as a 3x3x3 array. Number each piece from 0 to 4 and let ~~index~~ 5 be a free space. Each cube will store the pieces next to it as well as their axis on which it contacts the cube. This allows us to find free spaces next to a given piece, where we can place a cube.

For each piece, pick an arbitrary empty space for the first cube. Then for each remaining cube that goes on the piece, pick a random empty space adjacent to one of the already placed cubes. If none are available, restart.

Assigning cubes to pieces: (number of cubes per piece)

1) Generate a base distribution with as many max-sized pieces as possible.

1.1) $maxCubes \times numMax + filler + minCubes \times numMin = size^3$
Where minCubes and maxCubes are the min and max number of cubes in a piece, numMin and numMax are the number of min and max sized pieces, size is the side length of the puzzle cube in cubes, filler is a value between minCubes and maxCubes to make sure that the total cube count is $size^3$

1.2) $numMax = \frac{size^3}{maxCubes} - numMin - 1$, numPieces = number of puzzle pieces

1.3) $filler = size^3 - numMin \times minCubes - numMax \times maxCubes$

1.4) $filler \in [minCubes, maxCubes]$, or.
$minCubes \leq size^3 - numMin \cdot minCubes - numMax \cdot maxCubes \leq maxCubes$.

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1.5) Substitute ~~maxNumMax~~ $\leq$ ~~size³~~ numPieces - numMin·minCubes -1 to get ~~size³~~ minCubes $\leq$ size³ - numMin·minCubes - ~~size³~~ numPieces - numMin·minCubes -1)·maxCubes $\leq$ maxCubes, numPieces = number of puzzle pieces.

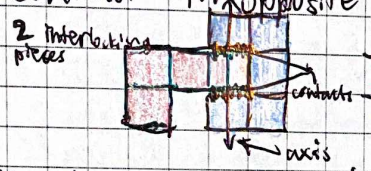
1.6) Rearrange to get numMin $\leq$ (size³ - maxCubes·numPieces)/(minCubes - maxCubes)

2) Randomly move cubes from pieces with more cubes to pieces with less cubes in a way that ~~doesn't~~ keeps the list in decreasing order.

Checking for interlocking:

Defining interlocking:

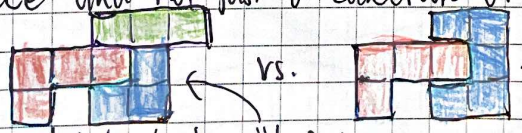
Two pieces are considered to be "interlocking" if they ~~move~~ make contact in opposite directions on the same axis:



contact directions & face opposite to each other

Checking for interlocking:

1) Check contacts in each axis.
2) for each contact in a given axis check ~~if~~ the sign (+/-) of the difference in the corresponding coordinate to the axis for the cube in the piece and the other cube it contacts
3) if there is at least one positive and negative in at least one axis, the piece interlocks with something
4) also check if at least one piece interlock with another piece and not just a collection of pieces.



red interlocks with 2 pieces vs. red and blue interlock

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TITLE The Algorithm Cont'd PROJECT Puzzle Cube

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Checking for Uniqueness Among all pieces:
Compare every piece to every other piece and see if they are congruent. Make sure no two pieces are congruent.

Congruent definition:
two pieces are congruent if one can be transformed into the other using only rotation, reflection, and translation.

Checking congruence:
1) Check the distances between the midpoints of every cube in a piece to the midpoints of every other cube in the piece.
2) Sort the distances from smallest to largest
3) repeat steps 1-2 for the other piece
4) check if the sorted lists of distances are the same. If they are, the pieces are congruent.

Putting it all together:
1) Generate distribution of cubes numbers for each piece.
2) Generate pieces
3) Check for interlocking and uniqueness
4) if either check in step 3 fails, regenerate from step 2.

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PROPRIETARY INFORMATION

TITLE Inferences about Cubes PROJECT Puzzle Cubes

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According to the data collected from the wooden cubes sampled, it is highly unlikely that the true mean size is actually 0.75 inches.

Stats from my data:
sample mean size $\bar{x} = 0.7562$ inches
sample standard deviation: $s_x \approx 0.009135$ inches
standard error $SE_x = s_x/\sqrt{n} = 0.001569$ inches
sample size n: 34 cubes
t-value: $t = \frac{\bar{x}-\mu_0}{s_x/\sqrt{n}} = 3.9614$
P-value: 0.0001877.

The probability of getting a sample mean of 0.7562 inches or greater with a sample size $n=34$ cubes is about 0.0001877, assuming that the true mean cube size $\mu_0 = 0.75$ inches.

It is clear that these errors are not due to random chance alone, and that the true mean cube size is greater than 0.75 inches.

Running a 95% t-confidence interval, we are 95% confident that the true mean cube size is between .753 to .759 inches.

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TITLE Cube manufacturing **PROJECT** Puzzle Cube.

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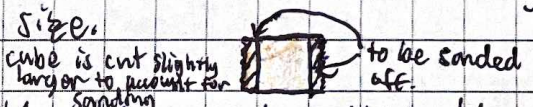
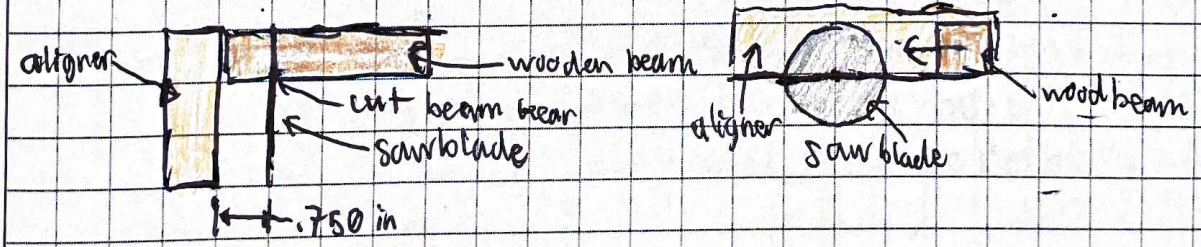
Cubes are probably manufactured by Woodworks, according to the buyer. (Mr. Carpenter).

Researching their manufacturing process yielded no results on Woodworks' manufacturing process specifically, although ~~some~~ other methods of manufacturing wooden cubes ~~were~~ was found, which involved taking wooden beams and using tools such as table saws to cut them into cubes. The cubes are then sanded and finished before finally being inspected.

However, these ~~puzzle~~ wooden cubes are not finished, and two sides (where the beam was cut) are slightly rougher than the rest. These cubes might be manufactured with the same machines as the cubes that would be sanded and finished, ~~to~~ so some extra material was left to account for those sides being sanded ~~of~~ down to their desired size.



There can also be an error with alignment with the ~~saw~~ blade and the end of the beam:



Fixing this would require re-adjusting the aligner or replacing it altogether.

There could also be issues with inspection or a high tolerance.

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TITLE Cube manufacturing cont'd **PROJECT** Puzzle Cube

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Data from other people making puzzle cubes:
(mean (in) and standard deviation (in))

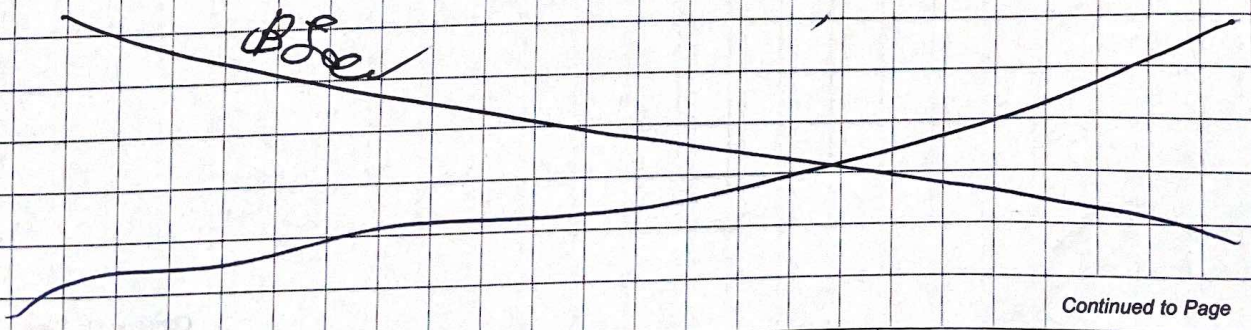
$\bar{x}$=mean, s_x=standard dev.

$\bar{x}$	s_x	$\bar{x}$	s_x	$\bar{x}$	s_x
.754	.005	.756	.005	.760	.108 ← outlier
.753	.007	.756	.009	.762	.007
.755	.008	.753	.003	.756	.009
.753	.008	.753	.009	.747	.012

the root mean squared of ~~Adding the squared~~ the standard deviations is $\sqrt{\frac{1}{12}\sum_{i=1}^{12} s_{x_i}^2} \approx 0.0078$, ignoring the outlier at 0.108.

the mean of the sampling distribution is $\frac{1}{12}\sum^{12}\bar{x}_i \approx 0.753$ inches, the median is also about .753 inches. this gives a 95% confidence interval of (.75216, .75384) inches for the true mean cube size. Given this, it might be helpful to move the aligner by about 0.003 inches closer to the saw blade when cutting out the cubes, or telling the machine to cut the cubes about .003 inches shorter. Also, ~~values~~ changes between 2.16E-3 and 3.84E-3 inches may also achieve better results.
If the cubes are still not well-sized around 0.75 inches, the machine may need calibration to improve its accuracy.

Since the standard deviation is about ~~0.78~~ 7.8E-3 inches, about 80% of the cubes manufactured should be within 0.010 inches of the mean (assuming cube sizes are normally distributed).



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TITLE Generated Designs PROJECT Puzzle Cube

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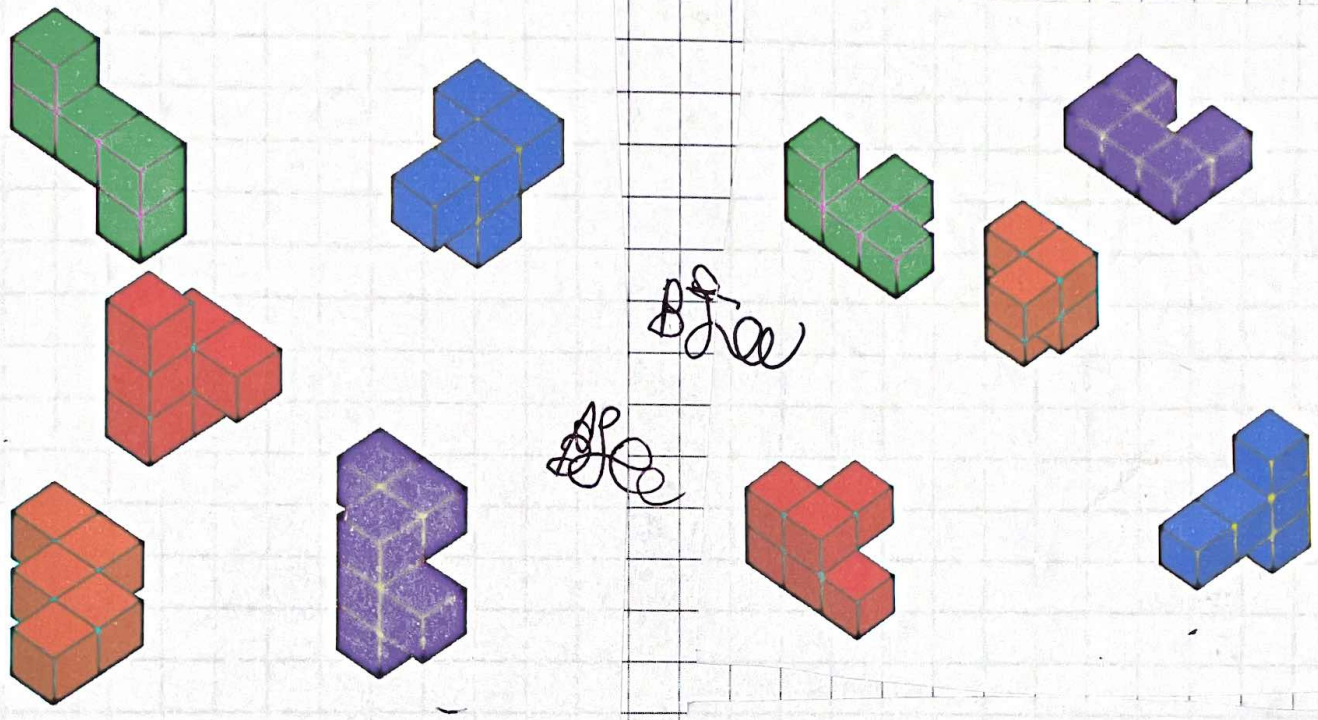
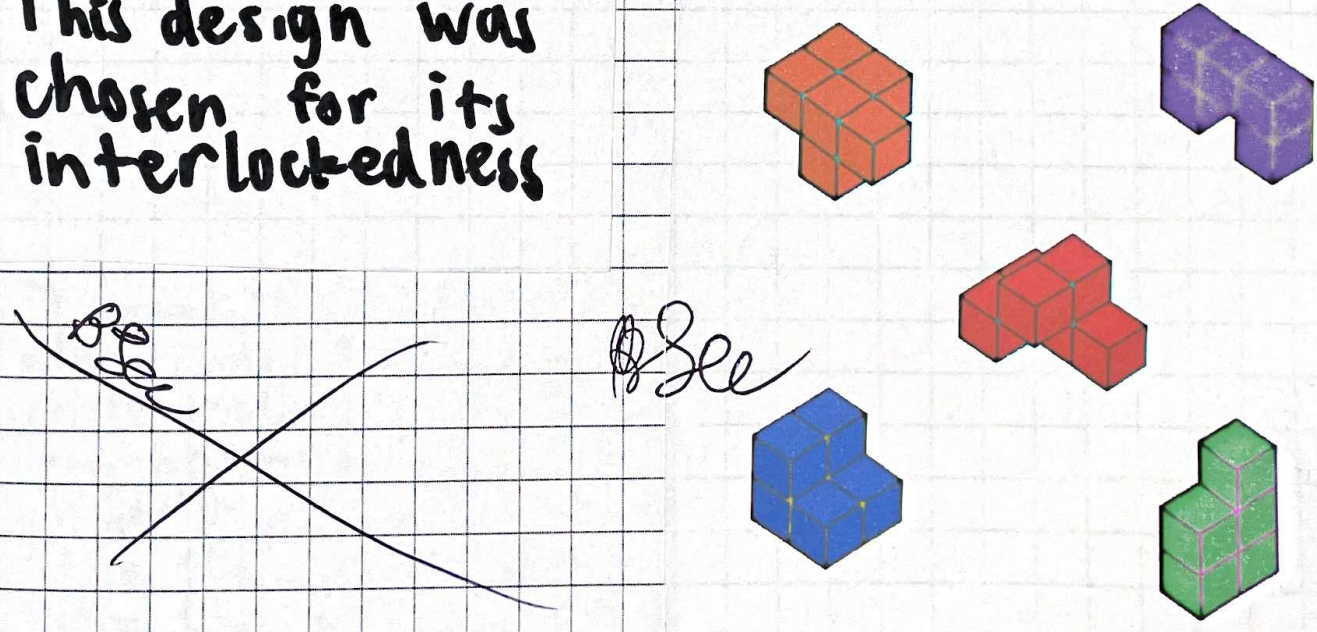
Here are several of the designs my algorithm generated:



This design was chosen for its interlockedness



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TITLE The Box PROJECT Puzzle Cube

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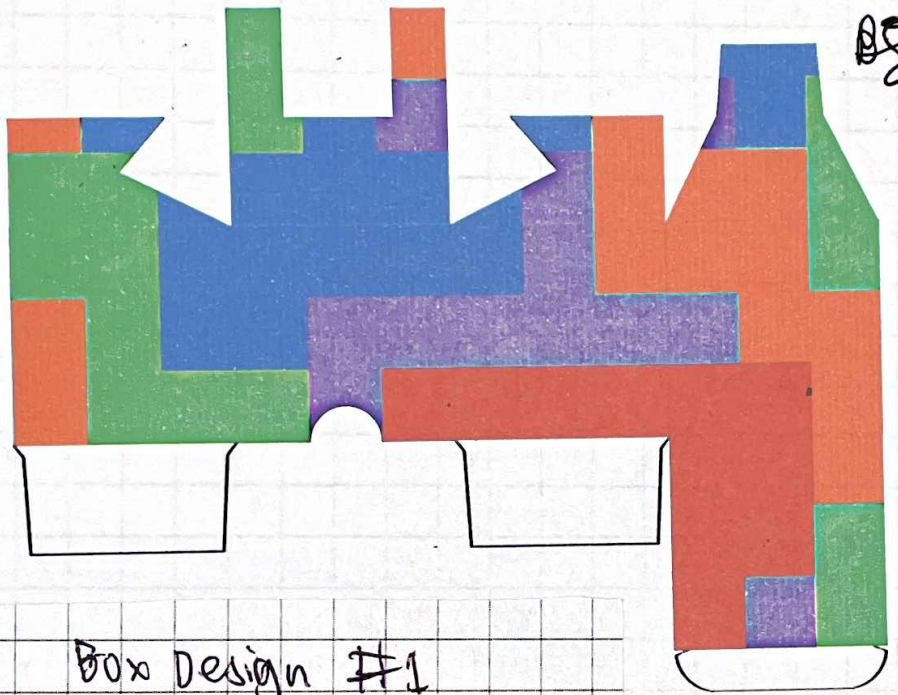
In order to make the Box attractive to kids it had to be aesthetically pleasing. At first, I tried putting the puzzle cube's outside as the box's texture, but it looked too random to be attractive:



Box Design #1

@See So, the colors were removed and a window and some text was added. It turned out that this simplified design was much more visually appealing. So a logo (generated by the algorithm I wrote) was added as well as some gradients for variation. (see next page).

To appeal to the children's parents, this had to seem educational. Initially, I had the idea to add a QR code leading to this ENB & the GitHub repository with my generation algorithm to the box, but then I realized that people could just scan it without buying the cube. Also, there weren't any good places to put the QR code on the box, so I ended up including a paper with the QR code in the box with the cube.

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TITLE The Box contd PROJECT Puzzle cube

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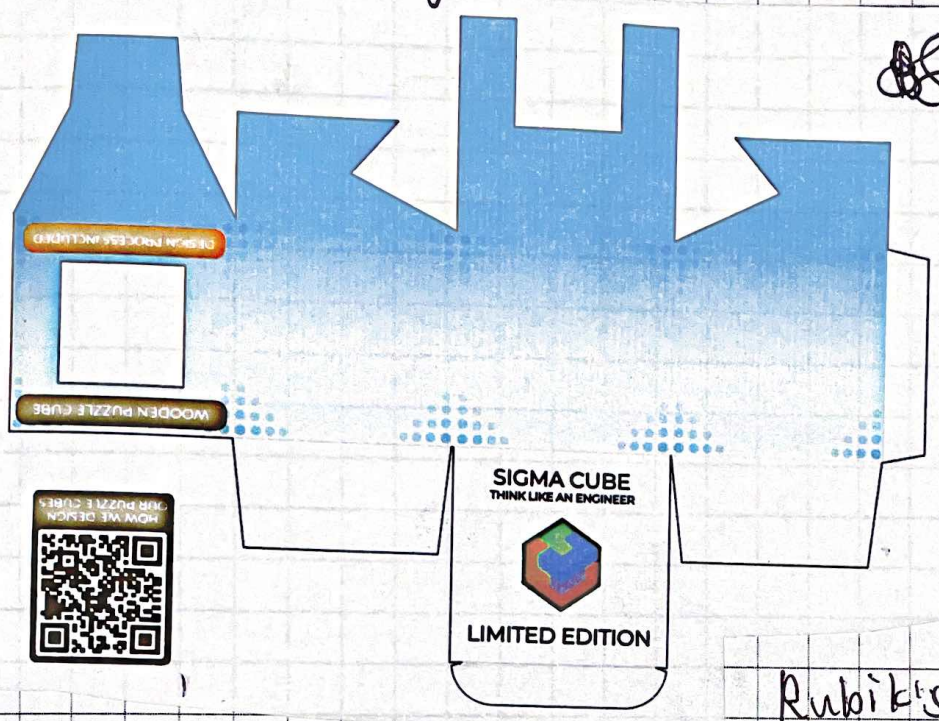
Final Box Design with QR code:



The words "Design Process Included" were added to indicate the QR codes existence, or something educational at the minimum.

In designing the Box's shape, I took heavy inspiration from Rubik's cube boxes, especially those of budget cubes that leave little room for anything but the cube.

The Box template was drawn on Vectr.com with each side being about 0.1 inches larger than the cube, or about 2.35x2.35x2.35 inches. This allowed the cube to have ~~true~~ enough space to go in & out of the box, but wasn't so big that it took up unnecessary space on shelves.

The box was printed on a glossy sheet of posterboard, which seems to require a pretty heavy duty printer to print on. Fortunately, I managed to coax it into the printer, cut it out, score it with some tweezers, & fold it up. The bottom interlocked with 0 difficulty & the cube slid in snugly. The window was made

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TITLE The Box Contd PROJECT Puzzle Cube

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from a plastic sheet from a pocket organizer & glued in with a glue stick.

The lid was able to open & close without difficulty, yet stays closed well enough so that it wont open on its own.

It can also be noted that kids (and people in general) tend to get excited by things that say "Limited Edition" as it contributes to its value artificially, ~~and~~ So this was added to the box to since very few of each cube model would be made due to the ability of the generator to create new designs in a mere blink of an eye. The colors can also be changed up to make them seem different.

Finally, The QR code was tested to make sure it worked before everything was packed into the box, completed. Now I just need to update the GitHub README to include these ENB Entries.

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