

## Technical Description

### The New Durable Rubik's Cube



#### General Overview

The Rubik's Cube is a 3-dimensional puzzle for all ages. The puzzle's goal is to simply match each of the six sides of the cube with the same color by turning each face one after another. With approximately 43 quintillion<sup>1</sup> possible arrangements, this simple toy offers a complex puzzle experience. This technical paper will focus redesigning the original 3x3x3 Rubik's Cube to improve its durability and reduce its complexity through means of using PVC tiles and ball bearing movement.

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<sup>1</sup> exactly 43,252,003,274,489,856,000 unique permutations

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## 1 History

Since the invention of the modern Rubik's Cube in 1974 by Ernö Rubik, this toy has sold over 350 million units, not including the sales of the many variations and imitations of the cube. From the first prototype to the modern Speed Cube, there has only been two major design changes in the Rubik's Cube.

### 1.1 Preceding Design (1970 - 1972)

Larry Nichols invented the original concept of the puzzle in 1970. His invention was a 2x2x2 combinational puzzle held together by magnets (figure 1.1). Nichols patented his invention on 1972, and called it the “Pattern Forming Puzzle and Method with Pieces Rotatable in Groups”<sup>2</sup>. Nichols’ puzzle design was unsuccessful in sales.

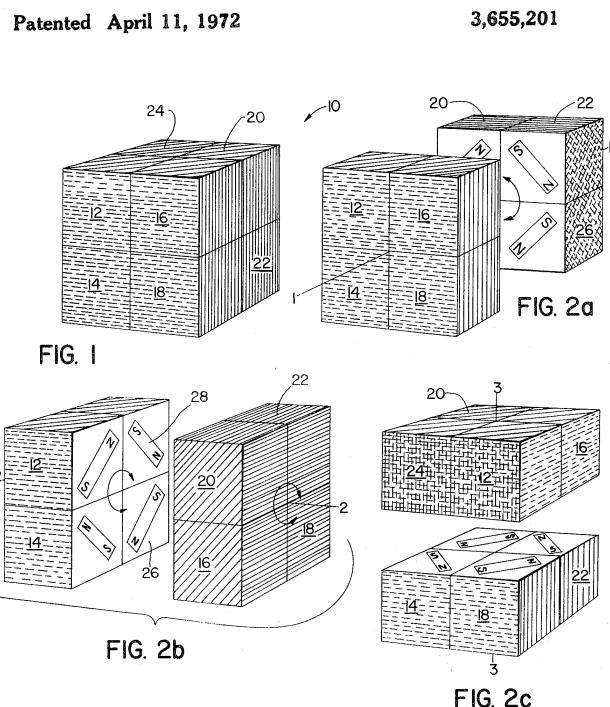


Figure 1.1: Nichols' puzzle patent

<sup>2</sup> Patent publication number [US 3655201 A]

## 1.2 Rubik's Design (1974 - today)

Ernö Rubik, a Hungarian sculptor and architecture professor, invented the design of the modern Rubik's Cube, originally called the Magic Cube (figure 1.2-a)<sup>3</sup>, in 1974.



*Figure 1.2-a: Rubik's original design (replica by Tony Fisher)*

In 1975 Rubik redesigned his cube to consist of plastic interlocking pieces, the same designed used today and the design discussed later in this paper. This design was far more durable than Nichols' magnetic design and became a success. In 1980, Rubik licensed his invention to the Ideal Toy Corporation (figure 1.2-b)<sup>4</sup> and his toy made its international debut in the same year. He also won the “German Game of the Year” award for the “Best Puzzle” in 1980.



*Figure 1.2-b: Original Rubik's Cube by Ideal Toy Corp.*

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<sup>3</sup> Image source: Tony Fisher

<sup>4</sup> Image source: John P. A. Carter

### 1.3 Modern Design (2013 - today)

Rubik's original design in 1975 was the only official Rubik's cube design until 2013. In 2013 the Rubik's Brand Ltd released the Rubik's Speed Cube. Rubik's Speed Cube consists of a spherical core (figure 1.3.1)<sup>5</sup>, allowing smoother turning of the faces and reduced chances of disassembly when turning the faces at high speeds. Albeit the Speed Cube having a better design, the original Rubik's Cube remains a widely popular option for the casual customer.



Figure 1.3: Partially disassembled Rubik's Speed Cube

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<sup>5</sup> Image source: Rubik's Brand Ltd

## 2 Design

The Rubik's Cube is a toy small enough to be carried comfortably in one hand; it is also big enough for the user to be able to manipulate the toy with both hands with ease. Each of the six faces of the cube is uniquely colored.

### 2.1 Dimensions

The cube measures 5.70 centimeters on each edge. Each face of the cube is partitioned into nine smaller even cubes, called cubelets, in a 3-by-3 arrangement, with each cubelet's outer-facing edges measuring 1.90 centimeters (figure 2.1).

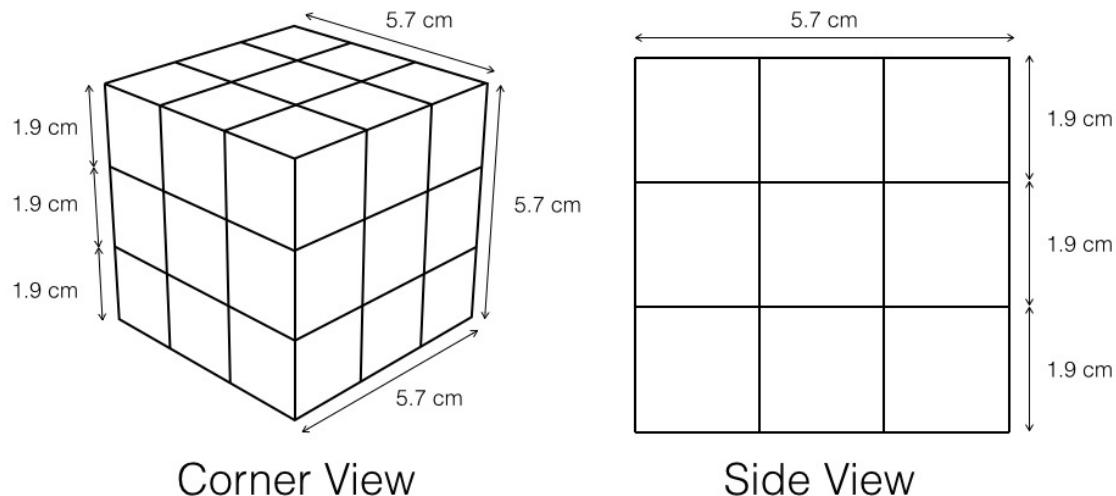


Figure 2.1: Rubik's Cube dimensions

### 2.2 Materials

The entire cube is composed of polymer-based plastic: either low density polyethylene (LDPE) or Polyvinyl-chloride (PVC). The only exception is the six metal screws and springs holding the central core of the cube together. The color-indication method on the cube is done using colored plastic adhesives composed of polyethylene terephthalate (PET).

## 2.3 Color

The standard Rubik's Cube follows a set color composition and arrangement. Any other differing color composition or arrangements from what is described in this section are not considered to be the standard Rubik's Cube.

### 2.3.1 Color Composition

The main cube is black in color except the color-indication components and the central core that is not visible at all times (figure 2.3.1-a)<sup>6</sup> when the cube is fully assembled..



*Figure 2.3.1-a: A blank Rubik's Cube*

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<sup>6</sup> Image source: of Rubik's Brand Ltd.

Each outer face of the cubelets has a specific color assigned. Color-indication adhesive components are squares measuring 1.70 centimeters, leaving a visible black border around each cubelet (figure 2.3.1-b).

Each of the six faces of the Rubik's Cube are indicated by unique solid colors: White, yellow, red, blue, orange, and green.

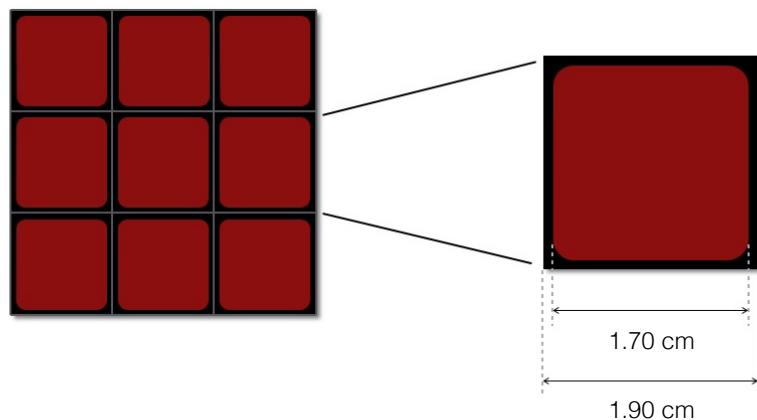


Figure 2.3.1-b: Outer dimensions of a cubelet and colored adhesive

At the toy's solved state, the same color is arranged on each face of the cube (figure 2.3.1-c)<sup>7</sup>, ergo each unique color is assigned to nine cubelet faces.

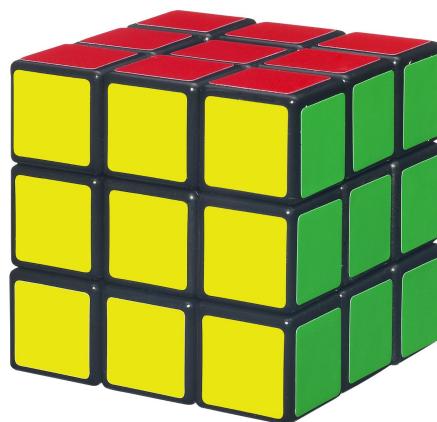


Figure 2.3.1-c: A solved Rubik's Cube

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<sup>7</sup> Image source: of Rubik's Brand Ltd.

### 2.3.2 Color Arrangement

The standard color-arrangement is as follows: Red is opposite from blue, orange is opposite from green, and white is opposite from yellow. The red, white, and blue color faces are adjacent from one another and are arranged in a clockwise manner (figure 2.3.2).

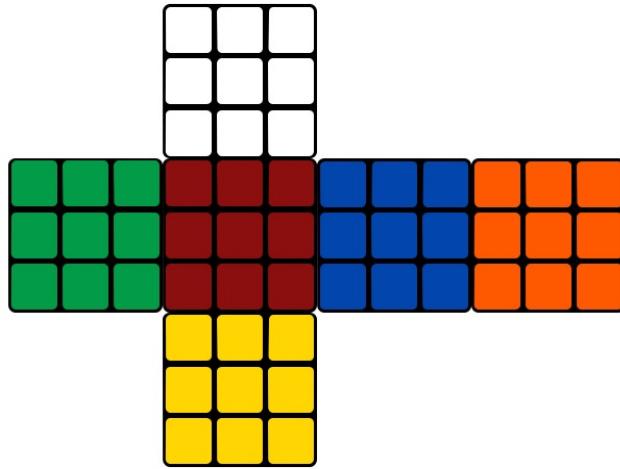


Figure 2.3.2: Color arrangement of the Rubik's Cube

The following table is the RGB values of the hues of the six colors used on the official Rubik's Cube.

Color	RGB Value		
	Red	Green	Blue
White	255	255	255
Red	137	18	20
Blue	13	72	172
Orange	255	85	37
Green	25	155	76
Yellow	254	213	47

Table 2.1: RGB values of the Rubik's Cube colors

## 2.4 Components

The entire cube is composed of one core and twenty-six cubelets, all held together by six metal screws, six springs and all the cubelets interlocking with each other.

### 2.4.1 Core

The center of the cube is a plastic axial core constructed as three cylindrical tubes intersecting one another at  $90^\circ$  from one another (figure 2.4.1). The length of each axial cylinder is 1.90 cm; the outer diameter is 0.76cm and the inner diameter at 0.25cm. The core uses six metal screws, one for each face, to hold the core and central cubelets together; the metal screws are installed in the cylindrical tubes of each axle.

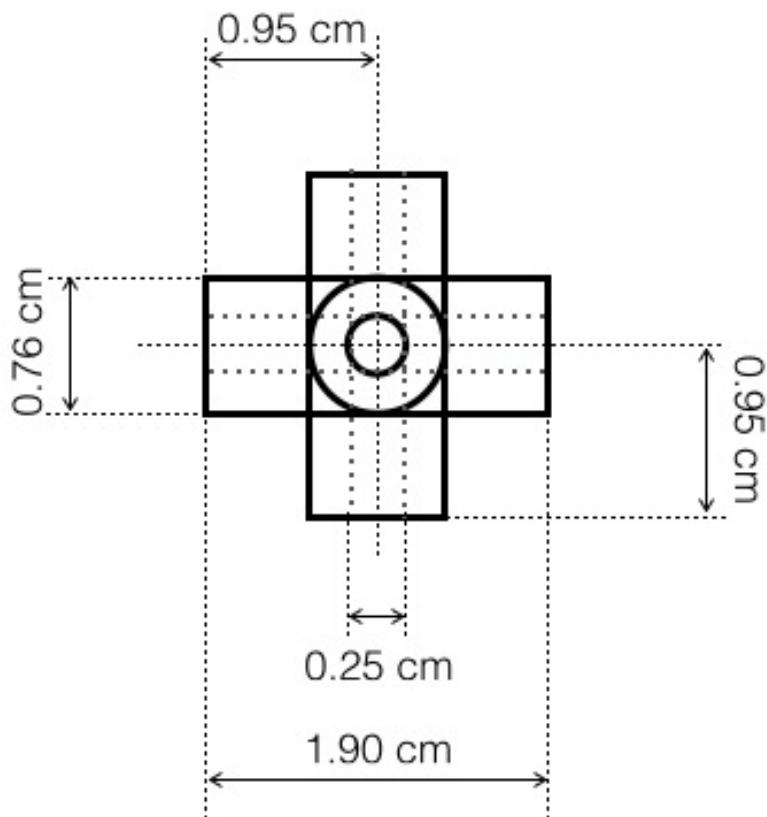


Figure 2.4.1: Schematic of Rubik's Cube core

## 2.4.2 Cubelets

The twenty-six cubelets can be categorized into three different types: edge, corner, and center. The Rubik's Cube is composed of twelve edge cubelets, eight corner cubelets, and six center cubelets. The colored adhesives are applied to the outward facing sides of the cubelet.

### 2.4.2.1 Edge Cubelet (figure 2.4.2.1)

The edge cubelet has two outward facing sides. There is a rectangular prism protruding from the inner edge of the cubelet, serving as the interlocking mechanism for the cube. The inner corner of the two faces adjacent to both colored faces are truncated in order for circular rotation with the other cubelets. The cubelet and the protrusion are hollowed out in order to reduce weight without significant compromisation to structural integrity.

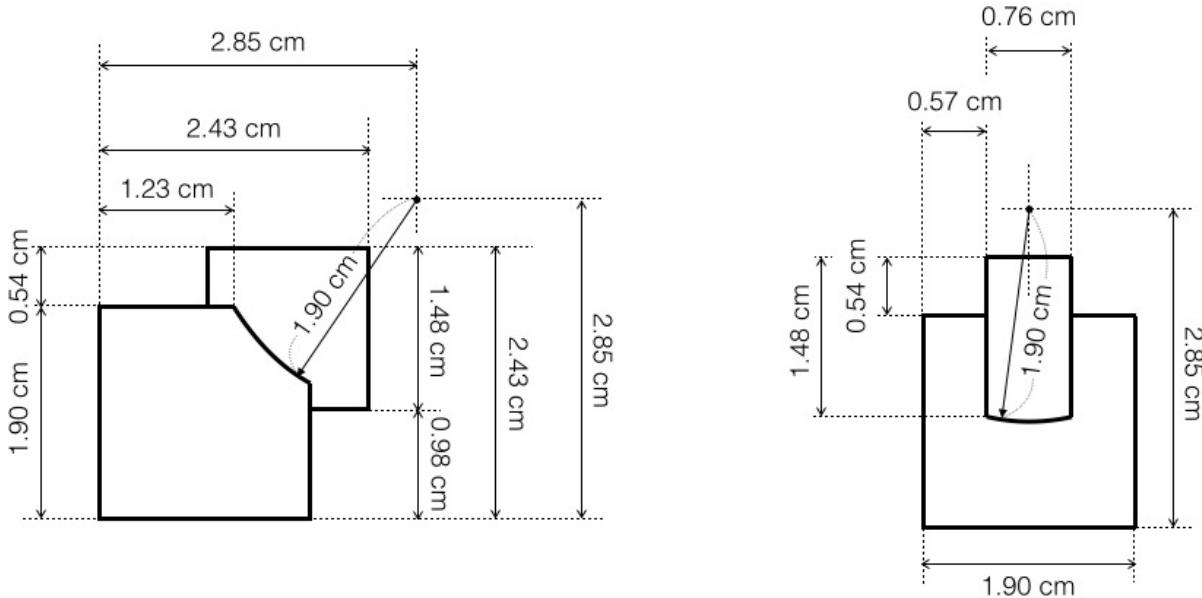


Figure 2.4.2.1: Schematic for edge cubelet

#### 2.4.2.2 Corner Cubelet (figure 2.4.2.2)

The corner cubelet has three outward facing sides. There is a smaller cube with three rounded faces protruding from the inner corner of the cubelet, serving as the interlocking mechanism for the cube. The rounded truncation of the protruding cube allows for circular rotation with the other cubelets. The corner cubelet is hollow on the inside to reduce weight but maintaining structural integrity.

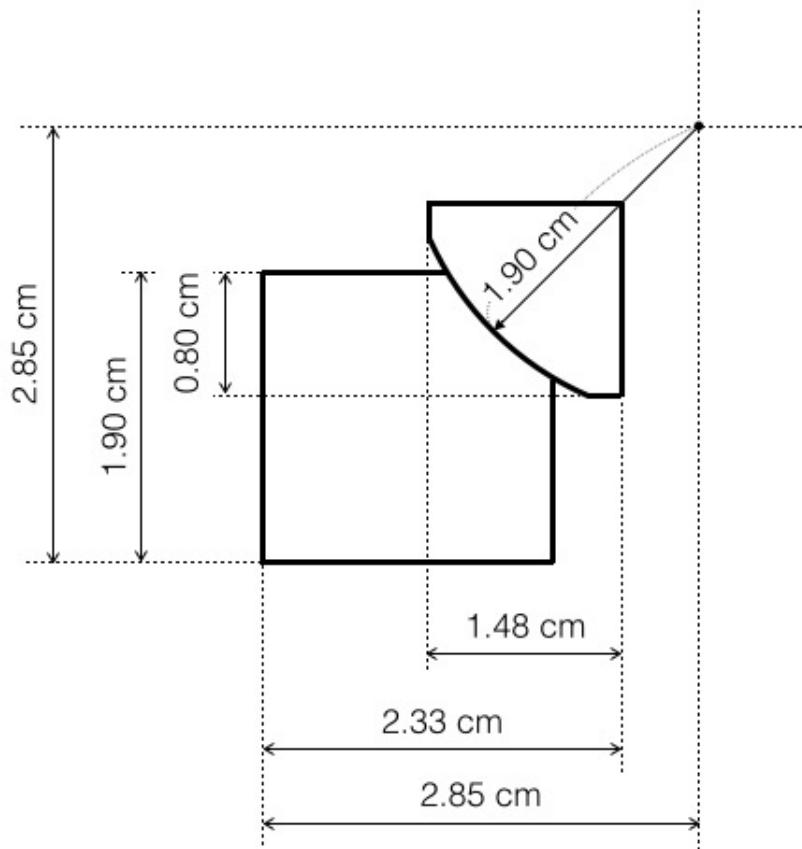


Figure 2.4.2.2: Schematic for corner cubelet

#### 2.4.2.3 Center Cubelet (figure 2.4.2.3)

The center cubelet has one outward facing side. The face directly opposite from the colored face has a cylindrical protrusion, hollowed at the center to allow a screw for attachment to the core. The four inner edges of the cubelet are rounded outwards in order to allow circular rotation with the other cubelets. The outward face is a square cap that snaps onto the cubelet to conceal the screw. Beneath the cap reveals the interior chamber of the cubelet for the installment and access to the spring and screw.

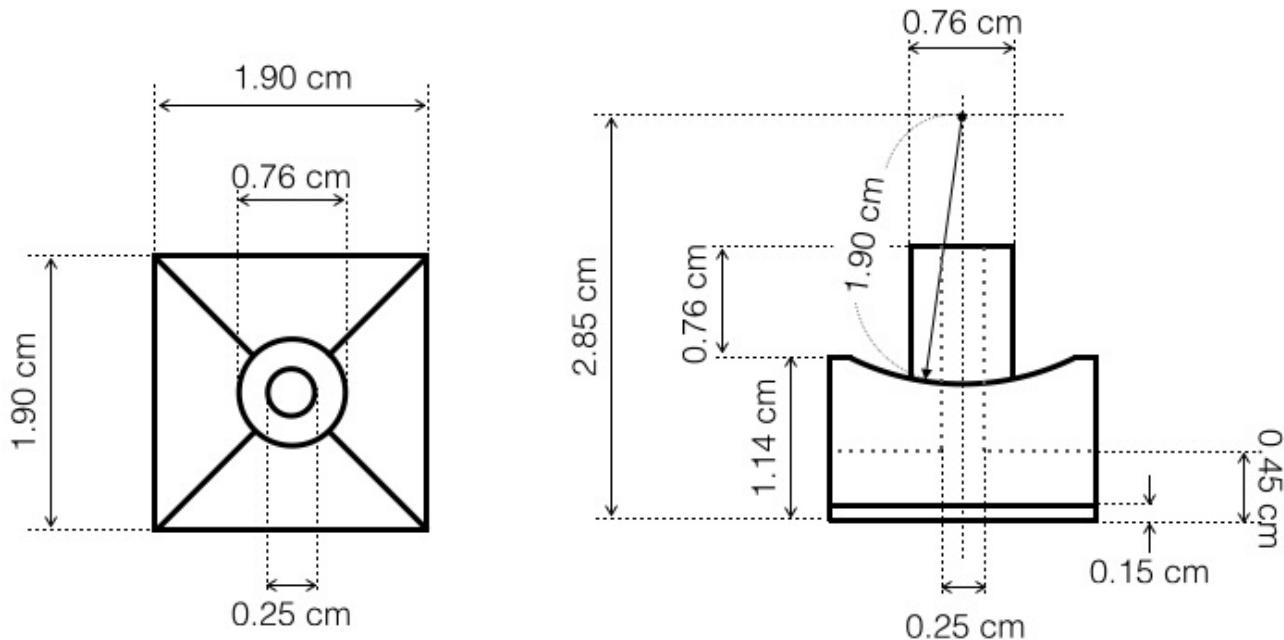
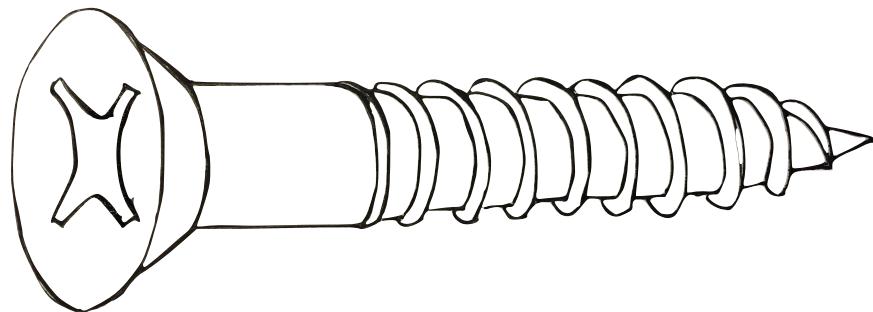


Figure 2.4.2.3: Schematic for center cubelet

### 2.4.3 Screws

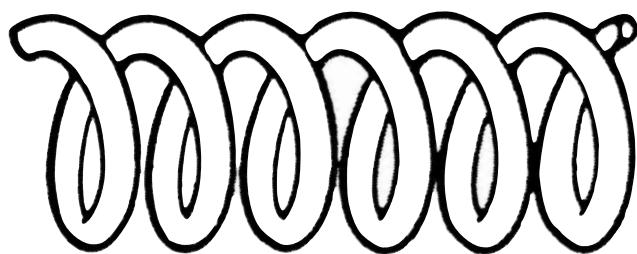
Six wood screws (figure 2.4.3) are used to hold the six center cubelets with the core. The smooth shank of the wood screw allows smooth sliding of the screw against the inner surfaces of the cubelet with each rotation of the cube, minimizing the damage done to the plastic surfaces through prolonged usage.



*Figure 2.4.3: Wood screw*

### 2.4.4 Springs

Six springs (figure 2.4.4) will sit between the wood screw and the inner chamber of the center cubelet. The spring will provide constant tension pulling the center cubelet against the core, ensuring the entire cube being held together as one single unit.



*Figure 2.4.4: Metal spring*

## 2.5 Structure

Each of the cubelets are interconnected to one another by the interlocking design of the protrusion of the edge and corner cubelet. The center cubelet serves as an axial pivot point.

### 2.5.1 Row Configuration

Each row is either configured as corner-edge-corner, edge-center-edge, or center-core-center. These row configurations will then be combined to form a layer configuration.

#### 2.5.1.1 Corner-Edge-Corner Configuration (C-E-C)

The edge cubelet rests between two corner cubelets. The protrusions of the two corner cubelets will be facing inwards towards the edge cubelet (figure 2.5.1.1). The sides of the corner cubelet's protrusions will rest against the inner edge of the edge cubelet, holding the corner cubelets in place. The top of the protrusions of all three cubelets will align flush with each other. The rounded edges of all three cubelet's protrusions will align to form part of a circle (denoted by dotted red line in figure 2.5.1.1).

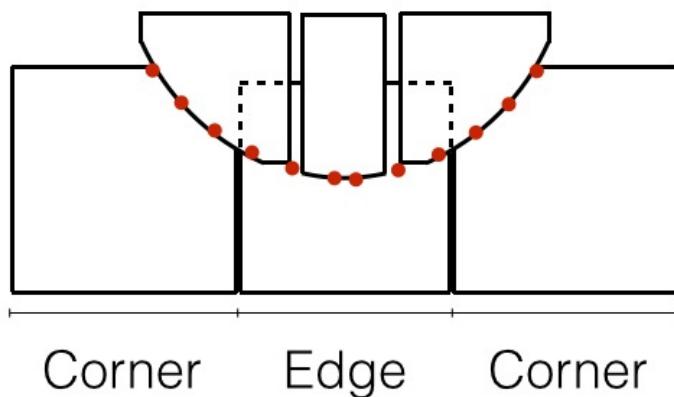


Figure 2.5.1.1: Row type C-E-C configuration

### 2.5.1.2 Edge-Center-Edge Configuration (E-C-E)

The center cubelet rests between two edge cubelets. The protrusions of the two edge cubelets will be facing inward towards the center cubelet (figure 2.5.1.2). The bottom of the two edge cubelet's protrusions will rest above the inner edge of the center cubelet, holding the edge cubelets in place. The top of the center cubelet's protrusion will rest below the top of the edge cubelet's protrusion; this recess will make room of the core's axial cylinders to connect with the center cubelets. The rounded edges of the cubelets will align to form a part of a circle (denoted by dotted red line in figure 2.5.1.2).

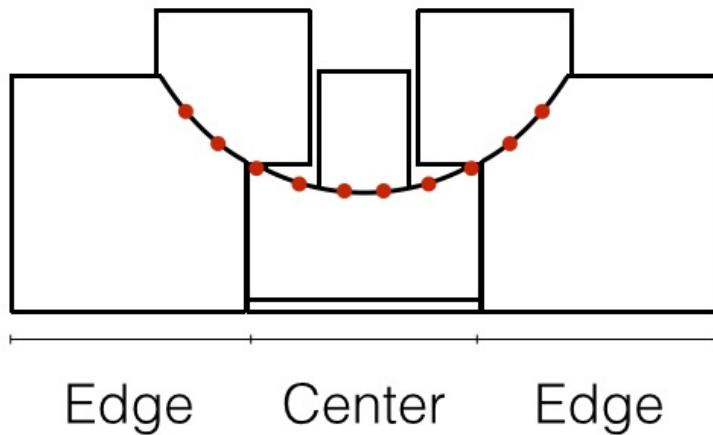


Figure 2.5.1.2: Row type E-C-E configuration

### 2.5.1.3 Center-Core-Center Configuration (C-C-C)

The cube core rests between two center cubelets. The two center cubelets are connected to the core by means of the wood screw. The wood screw will be threaded through the spring, inserted, and fastened through the center cubelets. The cap will then be placed onto the center cubelet to conceal the spring and screw (figure 2.5.1.2).

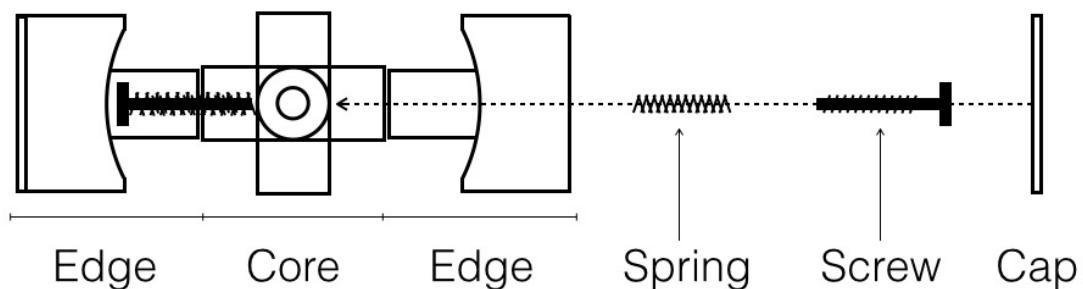


Figure 2.5.1.3: Row type C-C-C configuration

## 2.5.2 Layer Configuration

Combining the three row configurations will result in the layer configurations. There are two layer configurations: face layer and center layer. These layer configurations will then be combined to form the entire cube.

### 2.5.2.1 Face Configuration

The face layer configuration is composed of two C-E-C rows and one E-C-E row configuration. The two C-E-C rows will sandwich the single E-C-E rows (figure 2.4.2.1). The corner cubelet's protrusions will be resting against the two adjacent edge cubelet's inner side and adjacent the single center cubelet's inner corner. The edge cubelet's protrusions will only be resting against the center cubelet's inner edge. The center cubelet's inner edges will be holding all other eight cubelet in place, interlocking each cubelet with one another. The rounded edges of the protrusions of the cubelets will form a circle, serving as the rotational track for each layer to rotate against the other layers (denoted by dotted red circle in figure 2.5.2.1).

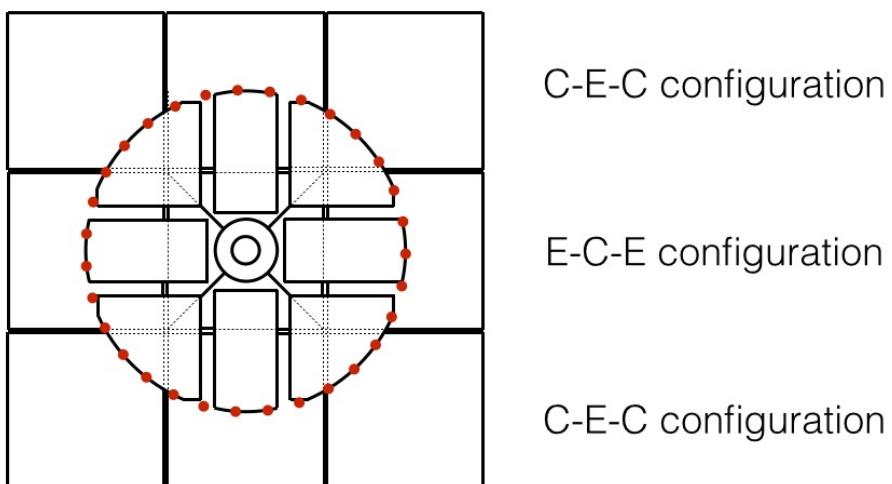


Figure 2.5.2.1: Face layer configuration

### 2.5.2.2 Center Configuration

The center layer is composed of two E-C-E rows and one C-C-C row. The two E-C-E rows will sandwich the one C-C-C row (figure 2.5.2.2). The protrusion of the edge cubelet will rest against the inner edges of the center cubelets, holding the edge cubelet in place. The core will be holding each of the four center cubelets together using the springs and screws. The rounded inner edges of all eight cubelets will form a circle, serving as the rotational track for this layer to rotate freely against the other layers (denoted by dotted red circle in figure 2.5.2.2).

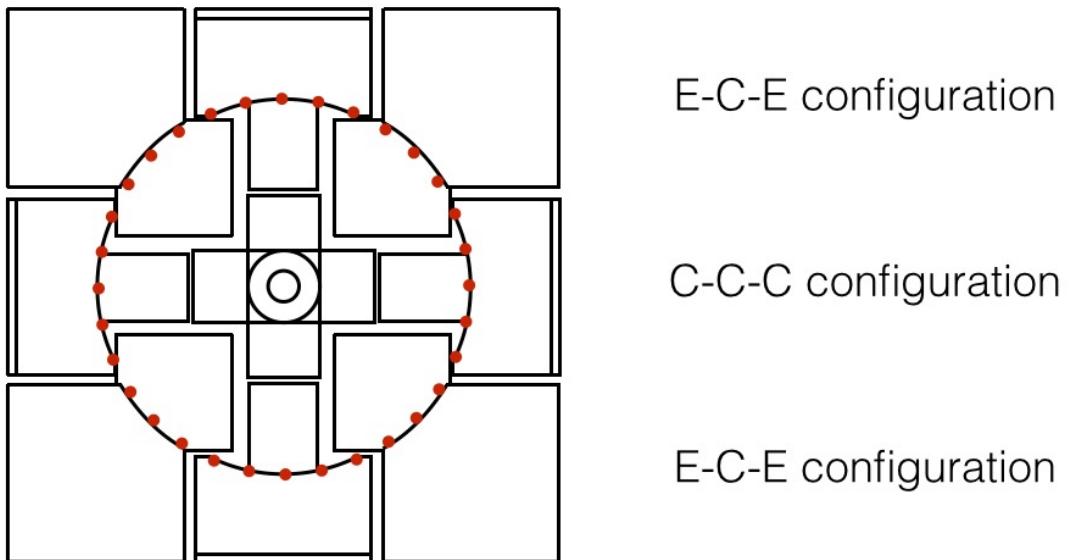


Figure 2.5.2.2: Center layer configuration

### 2.5.3 Cube Configuration

The twenty-six cubelets and the core can be combined to gather to form two face layers and one center layer. By combining the two face layers with the single center layer in a sandwich fashion (figure 2.5.3), the entire Rubik's Cube will be assembled and completed.

Each protrusion of the edge and corner cubelets sits against one another and against the center cubelet, and each center cubelet is held together with the core; this interconnection of the cubelets interlocks all twenty-six cubelets together.

In this completed configuration, there will be six circular tracks formed by the rounded inner edges of the cubelets. Each of these six circular tracks allows for each of the six layers to rotate: the core mechanic of the Rubik's Cube's design.

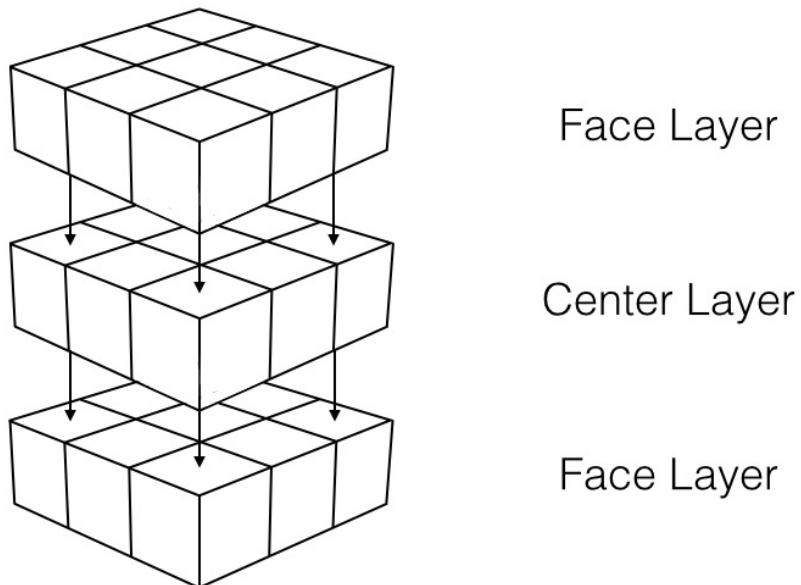
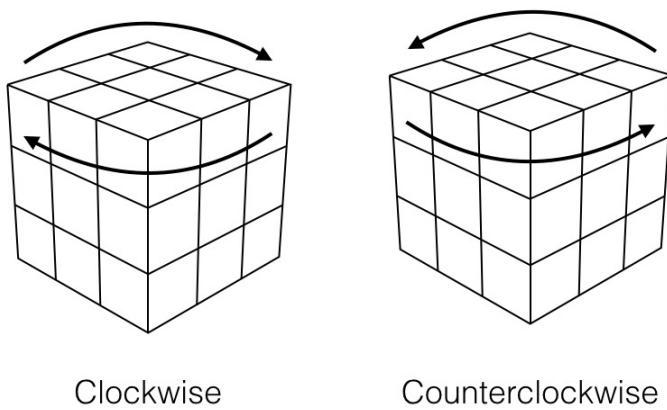


Figure 2.5.3: Combining layers to construct cube

## 2.6 Mechanics / Usage

The rearrangement of colors is achieved through rotating each face of the cube 90 degrees at a time. Each face can be rotated clockwise or counterclockwise (figure 2.5.4). With each of the six faces having two degrees of movement, this totals to twelve possible rotation options on the cube.



*Figure 2.5.4: Rotation methods*

With each 90 degree rotation, the corner and edge cubelets aligns with the edge and center cubelets of the adjacent face's cubelets, allowing for subsequent rotations to occur in any of the twelve choices.

Each rotation will displace all four corner and all four edge cubelets to the adjacent face corresponding to the direction of the rotation, transposing the arraignment of the colors. Only the center cubelets never displace due to the rotations pivoting around the center cubelets. Therefore the color of the center cubelet on each of the six faces indicate the color of the entire face when the puzzle is completed in its final color arrangement.

### **3 Redesign**

The traditional Rubik's Cube's design has been used for over forty years. However there is a flaw in the design that has never been fixed: durability. The two components of the Rubik's Cube that lacks durability are the color indication stickers and the rotational mechanism. The redesign will address both flaws.

#### **3.1 Color Indication Method**

The traditional method of using colored stickers on the Rubik's Cube has a major flaw in its durability. The corners of the stickers peel easily and is easily subject to wear (figure 3.1-a)<sup>8</sup>.

Even the professional grade stickers for professional speed-cubers has a lifespan of 750,000 rubs. This results in either constant replacement of stickers or of the entire cube itself.



*Figure 3.1-a: Typical worn down Rubik's Cube*

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<sup>8</sup> Image source: Helen W. Chang

In order to greatly improve the durability and lifespan of the color-indication method, PVC colored tiles can be used instead. This can be easily implemented by applying a strong adhesive or epoxy to the back side of the tile and binding the tile to the face of the cubelets (figure 3.1-b).

Plastic colored tiles eliminate the problem of the stickers wearing down. Furthermore, by using a strong adhesive to attach the tiles to the cubelet's faces, the tiles eliminate the issues of peeling, tearing, or being inadvertently removed.

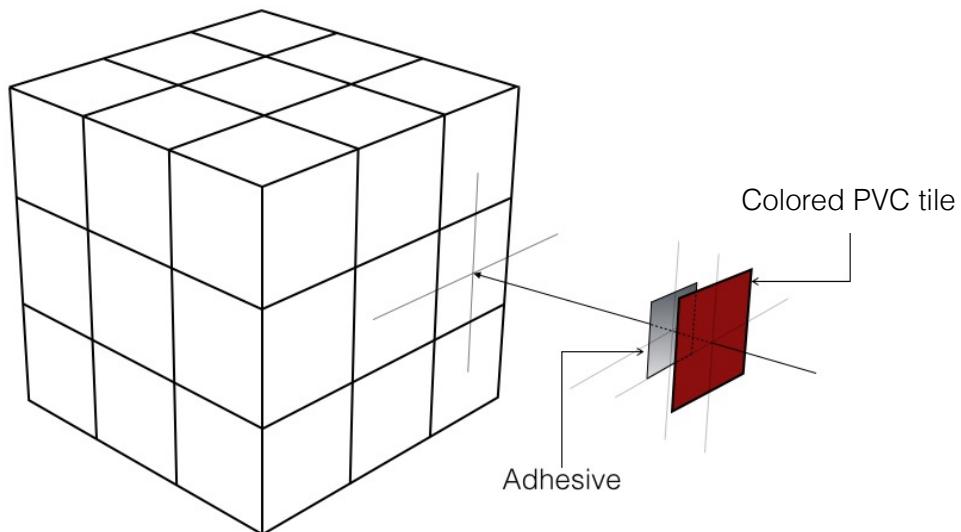


Figure 3.1-b: Application of colored PVC tiles using adhesives

## 3.2 Ball Bearing Movement

Instead of using a spring and wood screw to connect the core to the center cubelets, using a ball bearing can smoothen rotations, reduce the number of components, and reduce assembly steps.

### 3.2.1 Ball Bearing

The type of ball bearing used will be a deep-groove radial ball bearing. This component will be constructed from heavy-duty steel to ensure maximum durability. The ball bearing will be of a cylindrical shape, with the outer diameter at 0.50 cm, the inner diameter at 0.25 cm, and the height at 0.50 cm. Due to the small dimensions, the additional six ball bearings added to the Rubik's cube will not increase the overall weight by any significant amount.

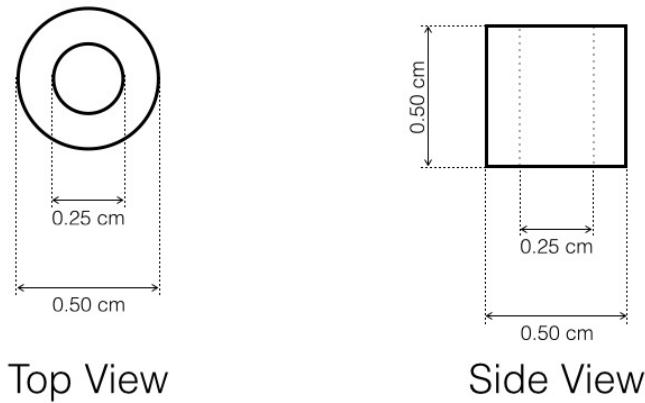


Figure 3.2.1.1: Schematic of ball bearing

### 3.2.2 Redesigned Components

This redesigned Rubik's Cube using ball bearing movement will consist the redesigning of two existing components, the center cubelet and the core. As a result, this redesign will eliminate three components in the original design: the wood screw, spring, and center cubelet cap.

### 3.2.2.1 Redesigned Core

To install the ball bearing onto the core, the core will now have an additional cylindrical protrusion from each of the six axial ends (figure 3.2.1.2). Each protrusion will measure 0.50 cm in length and 0.25 cm in diameter. Since wood screws are no longer used, it is no longer necessary to mill cylindrical channels down the middle of the axles. The core will still be composed of LDPE or PVC, ensuring the structural integrity of the protrusions, thus the protrusions will not likely be subject to breaking or fracturing.

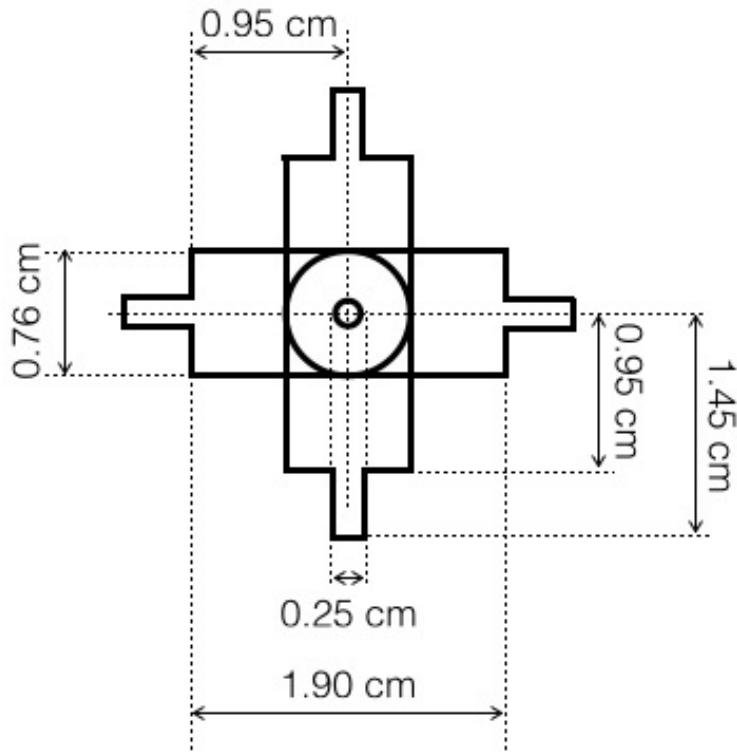


Figure 3.2.1.2: Schematic of redesigned core

### 3.2.2.2 Redesigned Center Cubelet

The cylindrical axle will have a cylindrical recess in order to house the ball bearing component. This recess will be milled a depth of 0.50 cm and a diameter of 0.50 cm. Due to the elimination of the wood screw and spring, the center cubelet no longer needs a cap nor interior chamber.

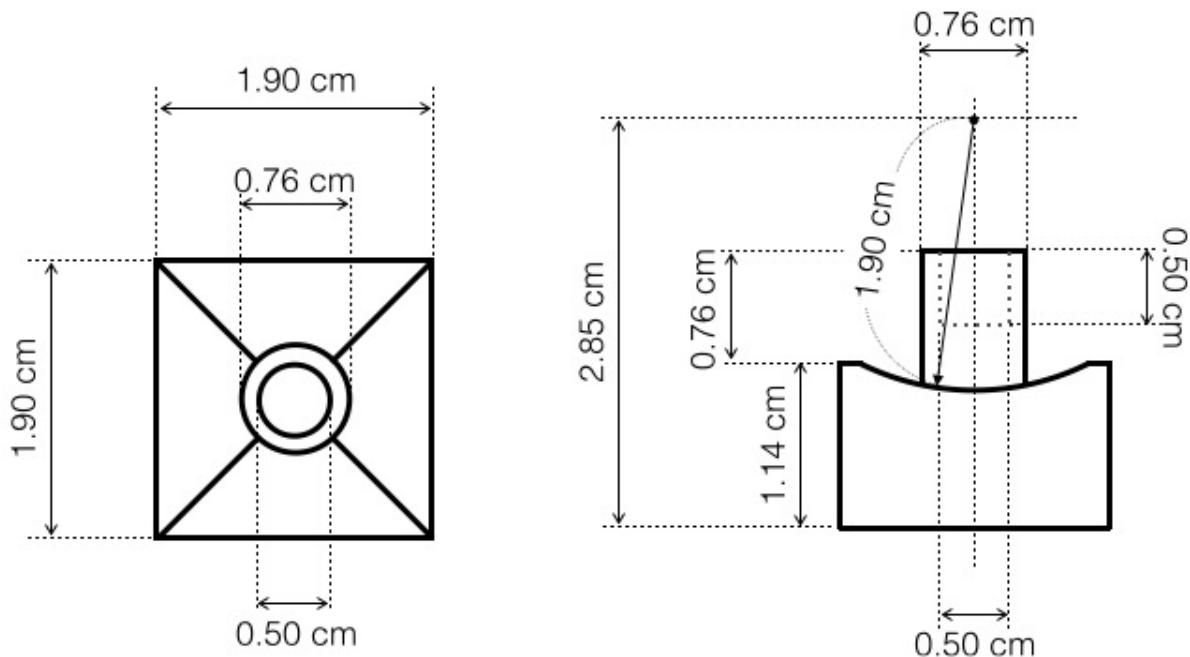


Figure 3.2.1.3: Schematic of redesigned center cubelet

### 3.3 Construction

Assembly of the ball bearing occurs in two steps. The ball bearing is first inserted onto the protrusion on the core's axles, the center cubelet will then be inserted onto the ball bearing afterwards (figure 3.3). The resulting construction will have the ball bearing acting as a rotational interface between the core and the center cubelet, housed onto the core's protrusions and inside the center cubelet's recess.

An epoxy or other binding agent will be used on the metal-polymer interface in the attachment of the ball bearing, eliminating the possibility of deconstruction of the ball bearing interface.

This construction replaces all core-center-cubelet attachment steps. All other procedures in the construction of the cube remains the same.

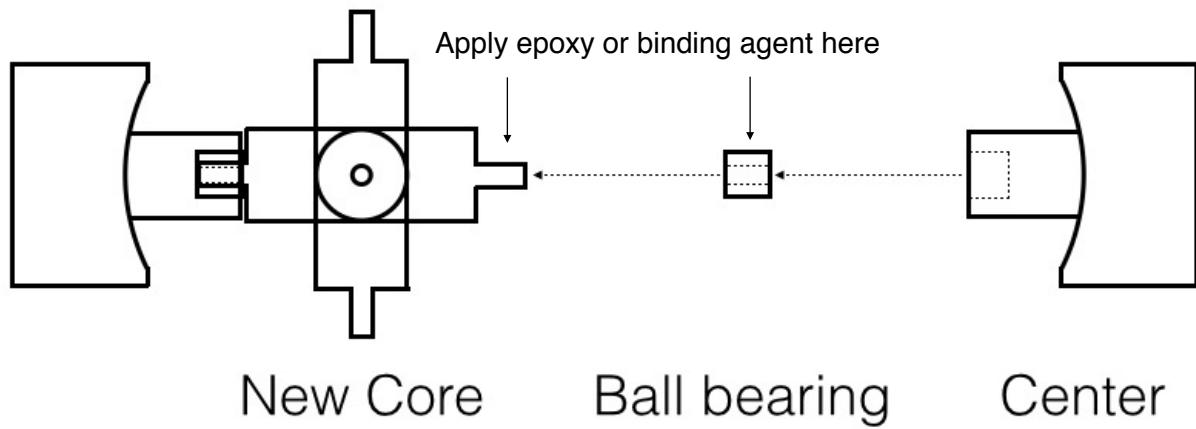


Figure 3.3: Assembly of ball bearing with the new core and center cubelet

### 3.4 Comparison

The following table summarizes the features and specifications between the original Rubik's Cube and the redesigned Rubik's Cube. Detailed discussion on each feature and specification will follow afterwards.

	Original	Redesigned
<b>Components</b>	99	87
<b>Rotation mechanism</b>	Spring and wood screw	Steel deep groove radial ball bearing
<b>Color indication method</b>	PET stickers	PVC colored tiles
<b>Layer extension</b>	Variable	Restricted
<b>Customzability</b>	Free	Restricted

*Table 3.1: Comparison between original and redesigned Rubik's Cube*

### 3.4.1 Components

The ball bearing component replaces the wood screw and spring components in the original cube; in addition, using the ball bearing eliminates the need to access the interior chamber of the center cubelet, therefore eliminating the need for the center cubelet cap. Both designs still require 54 color indication components (9 components for each of the 6 colors), 26 cubelets and a single core. The redesigned cube requires 12 less components than the original. Furthermore, the reduced components and simplified design reduces the number of assembly steps required, quickening the production of each unit. The following table lists the components in both the original and redesigned Rubik's Cube.

Original Rubik's Cube	Redesigned Rubik's Cube
Sticker (red) x 9	PVC Tile (red) x 9
Sticker (blue) x 9	PVC Tile (blue) x 9
Sticker (white) x 9	PVC Tile (white) x 9
Sticker (orange) x 9	PVC Tile (orange) x 9
Sticker (green) x 9	PVC Tile (green) x 9
Sticker (Yellow) x 9	PVC Tile (Yellow) x 9
Core x 1	Core x 1
Center cubelet x 6	Center cubelet x 6
Edge cubelet x 12	Edge cubelet x 12
Corner cubelet x 8	Corner cubelet x 8
Center cubelet cap x 6	Ball bearing x 6
Wood screws x 6	
Springs x 6	
<b>Total</b>	<b>99 components</b>
	<b>Total</b>
	<b>87 components</b>

Table 3.2: Table of components used in both original and redesigned Rubik's Cube

### **3.4.2 Rotation Mechanism**

The rotation mechanism of the original cube comprises of a spring and wood screw holding the core and center cubelets together. As a result each rotation is resisted by the frictional forces between the core and center cubelets. Using the ball bearing mechanism eliminates this friction, resulting in significantly smoother and more consistent rotations. The ball bearing is composed of steel, however due to the small dimensions of the ball bearing, this will not add any significant weight to the final product.

### **3.4.3 Color Indication Method**

The redesigned cube uses PVC colored tiles. PVC tiles is not subject to wear, loss of color when rubbed, nor will it peel after extensive use. However, these tiles will result in an increase in storage space, albeit not a significant amount. Taking into account off all the reduced number of components, the net storage space for all the components of the redesigned cube will still be less than that of the original Rubik's Cube.

### 3.4.4 Layer Extension

Layer extension refers to the degree in which the center cubelet can extend from the core.

In the original model, due to the spring mechanism, the center cubelet can be extended outwards (figure 3.4.4-a), ergo extending the entire face layer outwards (denoted by red line in figure 3.4.4-b) to a small extent. This allows for greater maneuverability and flexibility in the manipulation of the cube. The newer design binds the ball bearing to both the core and cubelet, no longer allowing this extension to happen. However the average user will not concerned with optimizing the performance of the cube, ergo not significantly impacting the target audience.

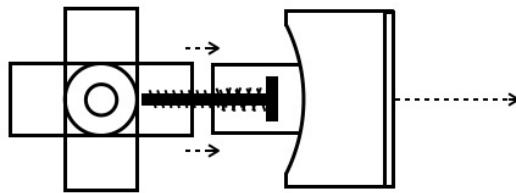


Figure 3.4.4-a: Extension of the center cubelet from the core

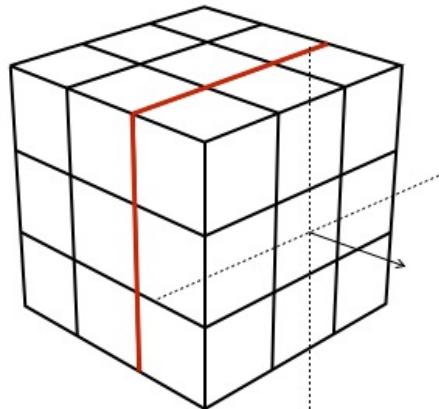


Figure 3.4.4-b: Extension of entire face of the Rubik's Cube

### **3.4.5 Customizability**

The original design of the Rubik's Cube allows its users to adjust the tightness of the screw and the stiffness of the spring to suit the cube's performance for each individual user. In the redesigned version, there is no such area for customizability. However, the average user of the Rubik's Cube will not consider customizing their Rubik's Cube; customization is only necessary for those who want to pursue speed-cubing and solve the Rubik's Cube competitively.

The consumers who want to customize their cube and pursue speed-cubing will be investing in the Rubik's Speed Cube instead of the classic Rubik's Cube; therefore, this restriction in the redesigned cube will not significantly impact the intended audience.

### **3.4.6 Improvements Summary**

From the consumer's perspective, the redesigned Rubik's Cube provides more durable color-indication components, as well as smoother and more consistent rotation movement. The reduced customizability and flexibility in complex maneuvers are unrelated to the target audience of this product.

From the supplier's perspective, the redesigned Rubik's Cube reduces the number of individual components in cube as well as reduced assembly procedures, allowing faster and cheaper production.