SPIN WHEEL

PRODUCT DESIGN SPECIFICATION

(DRAFT)

MAE 5630/4631
Advanced Product Design

NIRMAL A J L A
(na497)

ROBERT BRIDGES
(rcb354)

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1. Product Description Executive Summary

1.1 Team Name and Summary of Participants

Team Name: **SpinWheel**

Summary of Participants: **Robert Bridges & Nirmal A J L A**

1.2 Product Name

Product Name: **SpinWheel**

1.3 Problem you are solving

- Scroll wheel designs have remained largely unchanged since 1995.
- Current scroll wheels lack high precision, smoothness, and customization.
- Users (gamers, designers, professionals) struggle with either too little control or too much friction.
- Latency in wireless scrolling affects real-time interactions.

1.3.1.Reddit, Amazon Reviews, other evidence of problem

The three below Reddit links will direct two three different forums in which the discussion of why scroll wheels in general and in specific cases suffer from various issues.

First Reddit link
Second Reddit link
Third Reddit link
3dconnexion Forum
3dconnexion Forum

1.4. Customer hypothesis

If the Spin Wheel integrates a high-resolution magnetic encoder (AS5600) with customizable resistance and low-latency Bluetooth/USB connectivity, users will experience a 30% productivity boost due to enhanced scrolling precision, reduced lag, and tactical feedback, leading to higher adoption among professionals, gamers, and accessibility users while maintaining acceptable power efficiency, and device weight. Outweighing trade-offs like a more cluttered desk and the reliance on batteries.

1.5. Basic Functions of Product to solve problem

- **Customizable Controls** – Users can map different functions based on their workflow.
- **Precision & Durability** – Contactless sensing means no wear and tear.
- **Wireless & Portable** – Bluetooth connectivity for seamless use on any device.

- **Adaptive Haptics** – Provides feedback based on function (e.g., detents for scrolling, smooth rotation for zooming).

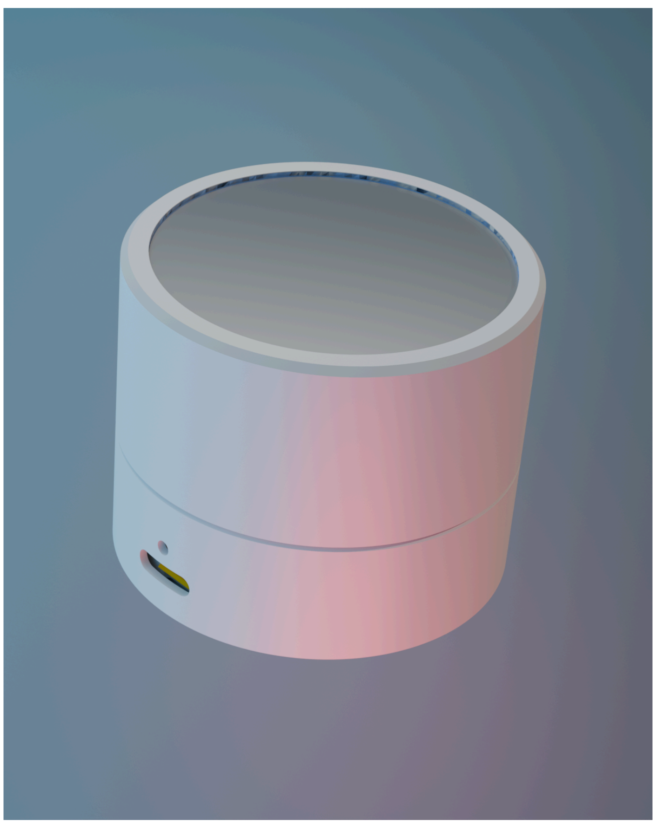
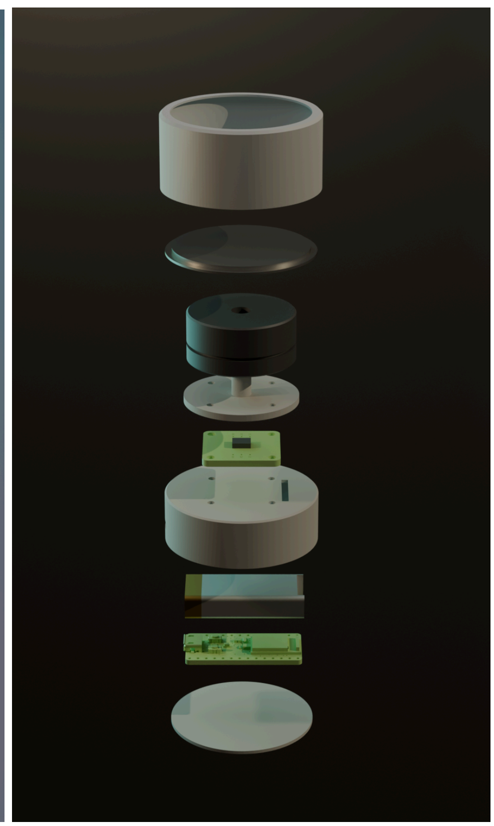
1.6. Service Environment Conditions

The Spin Wheel has an intended use of being on a desk indoors. It can be assumed that the device will be kept at room temperatures with minimal exposure to the outdoor environment.

1.6.1. Outside, inside, high/low temp, caustic, etc.

ABS can deform at high temperatures (>100°C), but normal use won't generate that much heat. We need to manage motor and battery heating to keep internal temps below ~60°C. (microcontroller produces less than 0.1w of heat)

1.7. Picture of highest level product refinement (CAD or physical)

The above two pictures showcase the SpinWheel in an assembled format as well as a deconstructed one.

2. Physical Description

2.1. List of Customer Requirements (C.R.'s)

The Spin Wheel's customer requirements derived from analyzing needs of creative and professional users including 3D modelers, gamers, video editors, and productivity specialists who handle large datasets and repetitive scrolling tasks. Our forum and review mining revealed two primary requirements: precision without sacrificing speed, with users rejecting current scroll wheels that are either too coarse for detailed work or too sluggish for navigation; and customizability of both sensitivity and tactile feedback ranging from smooth gliding to defined detents based on specific tasks.

Platform compatibility across operating systems via both Bluetooth and USB connections became essential as users regularly switch between devices, while space efficiency drove our decision to incorporate touch-enabled surfaces directly on the scroll wheel for gesture control without additional desk space. Battery longevity and mechanical robustness ensure consistent performance during extended professional use sessions, completing our core requirements set.

These carefully distilled requirements formed the foundation of our House of Quality analysis and guided our engineering targets and subsystem selection throughout development, enabling us to create a solution that addresses the shortcomings of existing scrolling devices while introducing innovative control capabilities within a compact form factor.

Customer Requirement	Description
Smooth, precise scrolling	Must offer fluid motion with no jitter and high-resolution response for CAD, video, and document navigation.
Cross-platform use	Should support Bluetooth Low Energy and USB HID across macOS, Windows, Linux, and potentially mobile platforms.
Customisable scroll feel	Ability to switch between detented and free-spin modes.
Durability / reliability	Must withstand repeated use without mechanical degradation; ideal for professional use environments.
All-day battery life	Rechargeable and efficient; should operate for extended periods without daily charging.
Additional control surface	The wheel should double as a capacitive touchpad for media control, gestures, and other custom functions.

2.2. Use of TRIZ throughout iterations

The iterative design of the Spin Wheel was guided by TRIZ principles as we addressed functional contradictions in modern input devices. Traditional scroll wheels compromise between tactility and speed, resolution and energy efficiency, and durability and user control. We resolved these tensions using Substance-Field modeling, contradiction mapping, and inventive principle application to develop innovative solutions that satisfy competing requirements simultaneously.

2.2.1. Substance Field Analysis

The Spin Wheel combines multiple sensing and feedback modalities—mechanical scrolling, magnetic encoding, capacitive touch, and haptic output—within a compact, handheld device. This creates a complex environment of overlapping substances and fields that can cause interference or inefficiency if not properly addressed. To systematically understand and resolve these interactions, we performed a Substance–Field Analysis:

Identified Substances:

Substance	**Description**
S1	User's finger *(source of input)*
S2	Trackpad surface *(input interface)*
S3	Magnetic encoder (*AS5600)*
S4	Device housing and structure
S5	Added shielding layer *(selected trackpad with shielding)*

Identified Fields:

Field	**Description**
F1	Mechanical force *(twisting, pressing, swiping)*
F2	Capacitive/electrical field *(touch sensing)*
F3	Magnetic field *(rotational sensing)*
F4	Information signal *(digital output)*
F5	Feedback field *(haptic or visual cues)*

Interaction Flow:

- **S1 → F1 → S2:** The user applies motion and pressure to the surface**.**
- **S2 → F2 → S4:** Capacitive trackpad translates gestures into signals.
- **S1 → F1 → S3:** The scroll action mechanically rotates the encoder shaft.
- **S3 → F3 → S4:** Encoder generates a magnetic field that changes with rotation.
- **S4 → F4:** Microcontroller processes signals into cursor/input movement.
- **S4 → F5 → S1:** Haptic motor provides detent feedback to the user.

Identified Issues:

These issues identified during Su-Field analysis revealed critical design challenges. Magnetic-capacitive field interference occurs when the touchpad and encoder share the same axis, causing magnetic fields to disrupt capacitive readings and potentially creating erratic input behavior. The precision versus feedback clarity problem stems from users struggling to interpret their current scrolling state without adequate tactile or visual cues, which diminishes the intuitive control needed for precision tasks in applications like CAD or video editing.

Su-Field Improvements Applied:

Problem	TRIZ-Inspired Solution
Field interference	Introduce S5, a shielding substance between trackpad and encoder, to block magnetic coupling.
Ambiguous input	Add F5, a feedback —via vibration —to disambiguate modes (scrolling vs. zooming).
Multi-function surface	Modify S2 to support both touch and rotation with distinct sensing zones

This Su-Field model allowed us to decompose a seemingly complex system into manageable, function-based units. Each pair (S1–S2, S1–S3, S3–S4, etc.) was evaluated for completeness and effectiveness, leading to specific improvements in mechanical layout, firmware filtering, and material shielding.

2.2.2. What engineering contradictions are you solving for?

The Spin Wheel faced several core contradictions during development. Precision vs. Speed required balancing micro-level control against fast scrolling, which typically demand opposing design strategies (high detent torque vs. low-friction glide). Customization vs. Reliability posed challenges as adjustable resistance, scroll modes, and detent profiles introduced mechanical and electrical complexity potentially compromising robustness. Multi-functionality vs. Clarity of Input emerged when using one surface for both rotational input and capacitive touch, creating potential ambiguity in interpretation during fast-paced tasks like gaming or editing. Low Power Consumption vs. High Feedback Quality highlighted the conflict between haptic feedback and Bluetooth connectivity draining battery quickly while attempting to maintain all-day wireless operation.

2.2.3. What are the historical solutions?

Historical commercial scroll wheel solutions have relied primarily on compromises rather than true contradiction resolution. Precision versus speed challenges were addressed through mechanical detents in devices like the Logitech MX Master or manual dual-mode switches requiring explicit toggling by users. Customization remained largely confined to software sensitivity adjustments without physical feedback or resistance changes. Multi-functionality was typically achieved by adding separate controls such as thumb wheels or additional buttons rather than integrating multiple functions into unified interfaces. The battery life versus performance contradiction was managed using low-energy Bluetooth profiles that often sacrificed critical responsiveness or polling rates. These approaches typically resolved only partial aspects of core user requirements while introducing additional drawbacks in bulk, complexity, or cost.

2.2.3.1. TRIZ solution

To address these contradictions, we applied TRIZ Inventive Principles to create innovative solutions. Dynamism (Principle 15) guided our firmware-based detent profiles and motor-controlled haptics, enabling contextual behavior changes without hardware modification. Merging (Principle 5) led us to place the diametric magnet inside the BLDC motor shaft, consolidating components and reducing complexity.

Local Quality (Principle 3) informed our differentiated input regions, with the trackpad's outer edge transitioning into scrolling for interface continuity. The Intermediary principle (Principle 24) drove our addition of magnetic shielding between the encoder and touch surface, preventing field interference while maintaining compact design.

2.2.4.What is your proposed solution?

Our solution integrates TRIZ principles into a unified platform addressing key contradictions efficiently. Electromagnetic detents provide user-adjustable tactile feedback that can be modified in real-time through firmware, solving the precision versus speed conflict. The high-resolution magnetic encoder ensures accuracy while eliminating mechanical wear points typical in optical or physical encoders, extending the device's operational lifespan.

A circular capacitive trackpad positioned atop the wheel enables gesture inputs without requiring additional desk space, while field separation is achieved using an integrated shielding layer beneath the trackpad. All components operate from a low-energy nRF52840 microcontroller that balances power efficiency with responsive input handling, ensuring all-day battery life while maintaining the performance required for professional applications.

2.2.4.1. How do you apply TRIZ solution (or other) to your specific problem

Our TRIZ principles were systematically applied to create practical engineering solutions. *Dynamism* enabled context-aware scroll modes that adjust between precision control and rapid scrolling based on application needs. *Local Quality* informed our dual-zone input design with specialized central rotation and outer multi-touch capabilities. *Intermediary principles* guided our electromagnetic shielding implementation for signal integrity, while *Merging* consolidated multiple functions into one ergonomic device, eliminating the traditional trade offs found in conventional input devices.

2.3. List of Engineering Parameters (E.P.'s) of Concept

The engineering parameters (E.P.'s) in the Spin Wheel project were derived from our House of Quality, mapping six customer requirements to five core functional elements that serve as measurable design levers ensuring technical decisions satisfy user needs. Each parameter was selected both for its individual contribution and its ability to connect multiple customer needs through shared components - the magnetic encoder (AS5600) enhances smooth scrolling, detent feedback precision, and durability through its contactless nature, while the nRF52840 microcontroller enables cross-platform compatibility, reduces input latency, and supports dynamic detent profiles, demonstrating how thoughtful component selection efficiently satisfies multiple requirements simultaneously.

E.P. #	Engineering Parameter	Functional Element
1	Rotational resolution	Magnetic Encoder (AS5600)
2	BLE/USB latency & protocol support	nRF52840 Microcontroller
3	Detent feedback profile control	BLDC motor for haptic feedback
4	Power budget and battery capacity	400 mAh Li-ion battery
5	Touch input and gesture mapping	Circular capacitive trackpad

2.4. House of Quality – C.R.'s vs. E.P.'s

The figure shows our House of Quality matrix mapping customer requirements to engineering parameters.

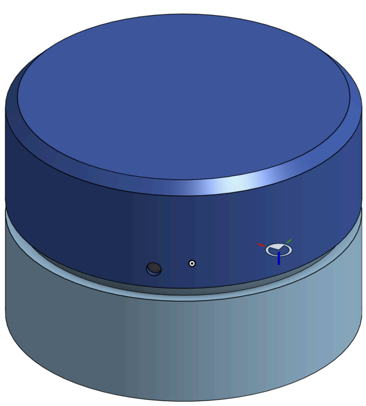
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Magnetic Encoder (AS5600)	nRF52840 Microcontroller	BLDC motor mounted scrolling	400 mAh Battery	Touch Trackpad (Circular)
					Direction of Improvement	▲	▲	◇	◇	
1		24%	10	9	SCROLLING (SMOOTH, PRECISE)	●		▽		
2		12%	5	9	CROSS PLATFORM USE		●	●		
3		24%	10	9	CUSTIMISABLE SCROLL FEEL (INDENTS, SENSITIVITY)	●	○	●		
4		17%	7	9	DURABILITY	●			▽	
5		10%	4	9	BATTERY LIFE		○		●	
6		14%	6	9	ADDITIONAL CONTROL		○			●
					Max Relationship	9	9	9	9	9
					Technical Importance Rating	8.57142	250	5.23809	2.38095	8.57142
					Relative Weight	41%	18%	25%	7%	9%
					Weight Chart					

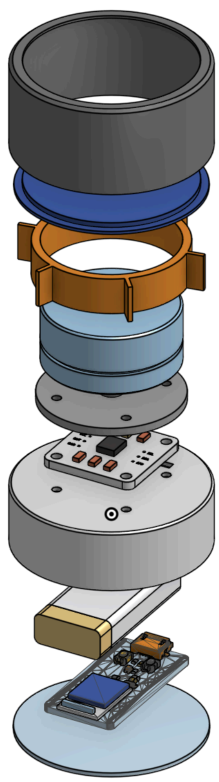
2.5. What is the embodiment of your solution?

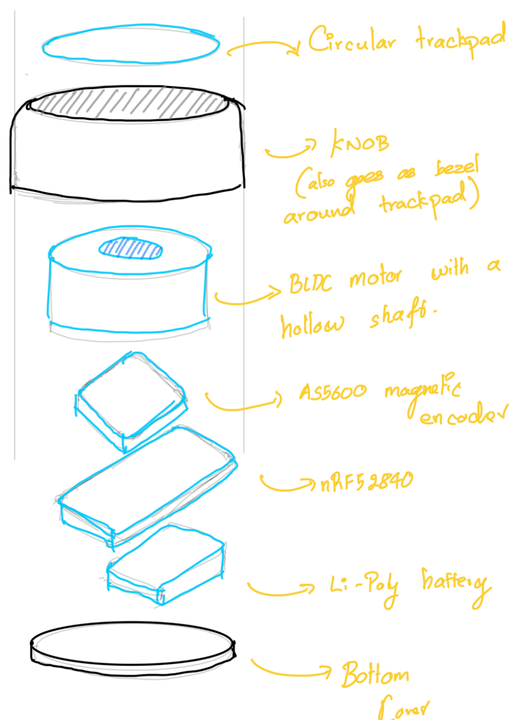
The Spin Wheel integrates ergonomic, electronic, and sensory systems in a compact 55mm cylindrical form. It features a central rotating disc with magnetic encoding, touch-sensitive outer ring, and internal BLDC motor for dynamic detent feedback. Two housing versions are offered: injection-molded ABS for mass-market affordability and CNC-machined aluminum for premium users. The internal architecture includes a custom PCB with nRF52840 microcontroller, 400mAh Li-ion battery, and modular encoder-motor assembly. All surfaces are ergonomically shaped to support various grip styles while enabling both wireless and wired operation.

2.5.1. Static Renderings

The figures illustrate both internal and external embodiments of the Spin Wheel. The assembled model shows the compact palm-sized enclosure housing all components. Exploded CAD views reveal the complete stack-up from circular capacitive trackpad through rotating knob, hollow-shaft BLDC motor, AS5600 magnetic encoder, nRF52840 microcontroller, and Li-Poly battery mounted to the enclosure.







2.6. Mechanical Analysis

This section outlines the preliminary mechanical performance assessment of the Spin Wheel. While full FEA simulations (static and dynamic) are still pending, the analysis presented here draws from published material properties for *ABS and aluminum*, estimated user force ranges *(2-10 N)*, and handbook-calculated stress limits based on component dimensions. This section will be updated once full finite element models are simulated and validated.

2.6.1. Analytical

Analytical estimates were used to assess whether the expected use forces—gripping, tapping, and scrolling—could exceed yield strength or cause structural failure.

Device dimensions and loading assumptions :

Scroll knob area:	~466 mm²
Maximum applied force (user press):	~10 N
Estimated applied stress:	$\sigma = \frac{F}{A} = \frac{10\,\mathrm{N}}{466 \times 10^{-6}\,\mathrm{m}^2} \approx 21.5\,\mathrm{kPa}$

This is orders of magnitude below the yield strength for:

ABS	~40 MPa
Aluminum 6061	~275 MPa

Thus, under realistic conditions, neither material is expected to deform plastically during use.

2.6.2. FEA

2.6.2.1. Static

To be updated with Von Mises and Animation for tapping and scroll(twist/shear) on rotary encoder

2.6.2.2. Cyclic Loading

A basic fatigue durability model was developed using conservative Weibull-based lifetime estimation, with parameters:

Shape (β): 2.0 – wear-dominated distribution
Scale (η): fitted to align with published cycle life expectations

Estimated life spans under fatigue:

ABS Version	~500,000 cycles (scrolls, presses)
Aluminum version	>2,000,000 cycles

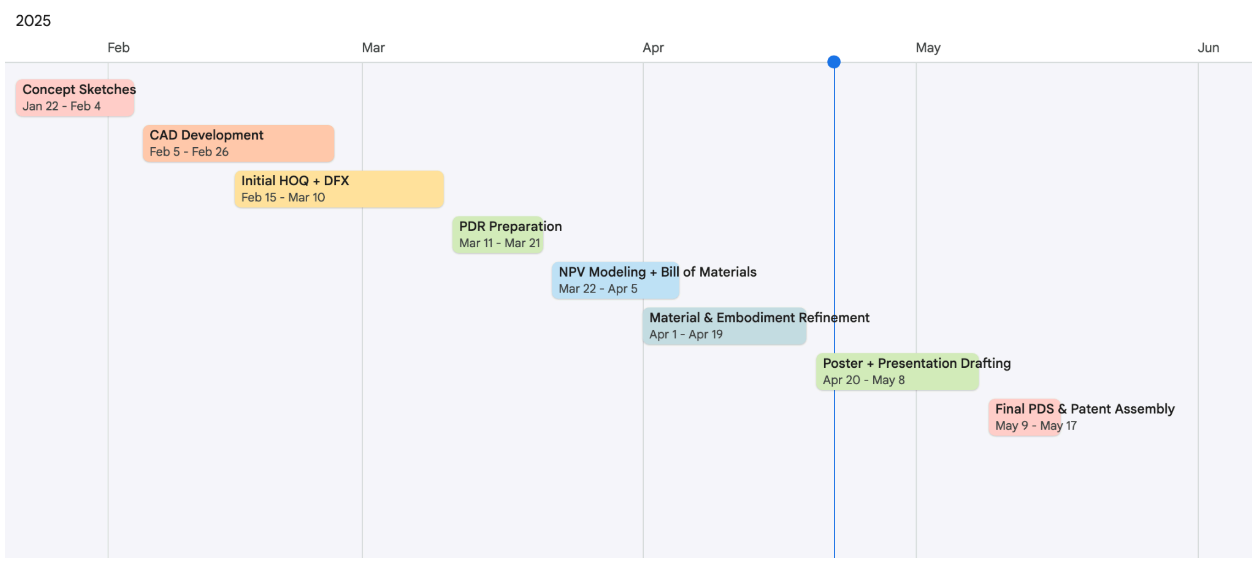
These are consistent with 1–2 years of daily use for productivity and creative applications. Component placement, PCB anchoring, and motor mounting surfaces were selected to minimize cyclic stress concentrations and decouple shear/twist forces from unsupported walls.

2.7. Project Deadlines

The Spin Wheel project was structured around key academic deliverables defined by the course timeline. The team advanced through conceptualization, embodiment design, cost modeling, and prototyping, with formal design reviews and documentation submissions guiding progress. All phases were scheduled to culminate in the final poster presentation and patent submission in May 2025.

2.7.1. GANTT chart

The Gantt chart below captures the full development timeline of the project from January 22 to May 17, 2025. Each phase is visualized with its actual start and end date, based on official course deliverables. Tasks are clearly separated and sequenced to reflect the structure of the semester. Key dates include Preliminary Design Review (PDR) on *March 21, 2025*, Poster Presentation Deadline on *May 9, 2025*, and Final PDS & Patent Submission on *May 17, 2025*.



2.7.2.Highlight Review

The Preliminary Design Review (PDR) was held on March 20, featuring the finalized House of Quality, preliminary CAD geometry, TRIZ contradiction analysis, and initial market hypothesis. Final Patent and PDS Submission was scheduled for May 17, encompassing detailed embodiment diagrams, manufacturing considerations, NPV cost forecasting, and IP documentation. These structured review milestones strategically aligned design decisions with customer requirements and project feasibility throughout development.

2.7.3.Highlight Total Completion Timeline

The total duration of the project was **January 22 to May 17, 2025**, amounting to approximately **17 weeks**. Concept development began in the first week of class, and final project deliverables—including the working prototype, poster, and documentation—were completed and submitted by the official course deadlines.

3. Market Identification (20%)

3.1. Target Market

The intended target market is in general any computer user. However, in order to narrow down to a more manageable market, the following list includes the main targets. Analysts, software, developers/ coders, accountants, english & history majors/ professors, creative professionals, gamers & streamers, and music producers & DJs. This list encompasses anybody who has to scroll through large files.

3.1.1.Market Size – IBISworld/other market reports

According to DataIntelo, as of 2023 the current market for scroll wheels is 1.2 billion. This makes sense as the scroll wheel is an everyday tool used by any computer user.

3.2. House of Quality – Competitive Analysis

Engineering Characteristics	Competitor Rankings 1-Poor, 3-Ok, 5-Excellent				
	CR	dell mouse	kensington track ball	3d connection space mouse	Microsoft Surface Dial
Expecter	Scrolling (Smooth, Precise)	4	4	2	4
Expecter	Cross Platform Use	5	5	3	1
Competetive advantage	Customizable Scroll Feel	1	1	3	3
	Durability	2	2	1	3
	Battery Life	5	5	3	3
Competetive advantage	Additional Control	1	1	4	3

4. Financial Requirements

4.1. Financial Executive Summary

The Spin Wheel project presents a strong financial case based on customer preference data and conservative modeling. Offering both ABS (mass-market) and Aluminum (premium) versions achieves market breadth and profitability. Consumer demand validation through CBC survey showed prioritization of additional control inputs, low latency, and premium feel, aligning with our dual form factor strategy. Both SKUs maintain profitability: ABS through low-cost injection molding for wide-market scaling, while Aluminum offsets higher manufacturing costs with premium pricing and shared NRE costs. The estimated market is 1.2 million units (95% ABS, 5% Aluminum), with NPV modeling confirming positive returns. Launch pricing is set at **$50 for ABS** and **$135 for Aluminum**, with sales forecasted using Bass Diffusion models and CBC utility functions.

4.2. Net Present Value

To assess the commercial viability of the Spin Wheel, we developed a detailed Net Present Value (NPV) model incorporating realistic burn rates, forecasted unit sales, production costs, and a 10% discount rate. The projection spans 36 periods (months), aligning with the expected diffusion and product adoption curve modeled via the Bass Diffusion approach. Total NPV for the ABS version is approximately **$3,035,521**, assuming a unit price of $50, production cost of $25, and monthly unit sales derived from the Bass modelThe financial model incorporates the following key cost factors:

Cost Category	Amount	Duration
Development	$120,000/month	9 months
Testing	$100,000/month	5 months
Tooling and Ramp-up	$100,000 total	2 months
Ongoing Marketing	$250,000/month	12 months

Additional model parameters include initial market introduction costs of $80,000/month from Month 10 to 22 and unit sales ramping from zero to approximately 70,000 units monthly, with peak sales occurring around Month 10. All cash flows were discounted at 10% monthly to reflect time value of money, confirming that the product reaches profitability within the projected 36-month horizon.

ABS Version – $50 Price Point

This version targets productivity workers, students, and cost-sensitive creators. Its injection-molded plastic housing keeps costs low and enables high-volume scaling.

Model Highlights:

Parameter	Value
Unit Price	$50
Production Cost	$25
Tooling & Ramp-Up	$100K
Unit Sales (M)	~1.14M
NPV (ABS)	$3,035,521

PROJECT NPV $ **3,035,521**

Base NPV
10,000,000

Changes from Base NPV

% of NPV	$ change
-69.6%	-6964479

MODEL VALUES

	first	last	base burn rate	adjusted burn rate	%Δ from base value	$Δ from base value
Development	1	9	-120000	-120000	0.0%	0
Testing	7	11	-100000	-100000	0.0%	0
Tooling and Ramp-Up Costs	10	11	-100000	-100000	0.0%	0
Market Introduction	10	22	-80000	-80000	0.0%	0
Ongoing Marketing Costs	11	22	-250000	-250000	0.0%	0
Unit Sales	1	36	38458	38458	0.0%	0
Unit Price	1	36	50	50.000	0.0%	0.00
Unit Production Cost	1	36	-25	-25.000	0.0%	0.00
Discount Rate (per time period)	10.00%					

Set input values in shaded cells.

Aluminum Version – $135 Price Point

This version targets professionals, streamers, and advanced users seeking higher durability and aesthetic appeal. It uses a CNC-machined aluminum shell and includes identical internals to the ABS version.

Model Highlights:

Parameter	Value
Unit Price	$135
Production Cost	$55
Tooling & Ramp-Up	$30K
Unit Sales (M)	~60,000
NPV (Aluminum)	~$2.7 Million

PROJECT NPV $ **2,717,365**

Base NPV
10,000,000

Changes from Base NPV

% of NPV	$ change
-72.8%	-7282635

MODEL VALUES

	first	last	base burn rate	adjusted burn rate	%Δ from base value	$Δ from ɔase value
Development	1	9	0	0	0.0%	0
Testing	9	11	0	0	0.0%	0
Tooling and Ramp-Up Costs	8	11	-30000	-30000	0.0%	0
Market Introduction	10	22	0	0	0.0%	0
Ongoing Marketing Costs	11	22	0	0	0.0%	0
Unit Sales	10	60	200000	200000	0.0%	0
Unit Price	1	60	135	135.000	0.0%	0.00
Unit Production Cost	1	60	-55	-55.000	0.0%	0.00
Discount Rate (per time period)	10.00%					

Set input values in shaded cells.

Combined NPV Outlook:

Version	Projected Sales	Unit Price	Production Cost	NPV Estimate
ABS	~1.14M units	$50	$25	$3.03M
Aluminum	~60,000 units	$135	$55	$2.7M
Total	~1.2M units	Mixed	Mixed	**$5.7M**

4.3. Pricing Policy

The Spin Wheel pricing strategy is anchored in two core insights: perceived utility across feature sets, as measured by our choice-based conjoint (CBC) analysis, and the cost-to-value ratio within targeted user segments. The conjoint results confirmed that users place high importance on additional control features, scroll resolution, and connectivity, justifying a premium for feature-rich variants. This guided our differentiation in pricing based on user willingness to pay and perceived feature importance.

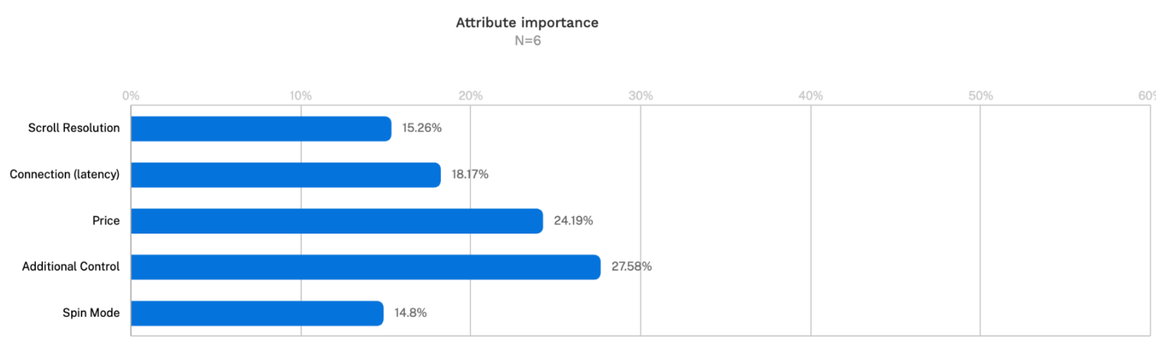
We implemented a two-tier pricing structure. The ABS version is set at $50, aligning it with high-end productivity peripherals like the Logitech MX Master. This tier is designed to appeal to a broad user base including students, CAD users, and digital creatives who value performance and configurability at a modest price point. The Aluminum version, priced at $130, is tailored toward design professionals, content creators, and premium accessory enthusiasts, offering enhanced tactile feel, material quality, and integrated trackpad functionality.

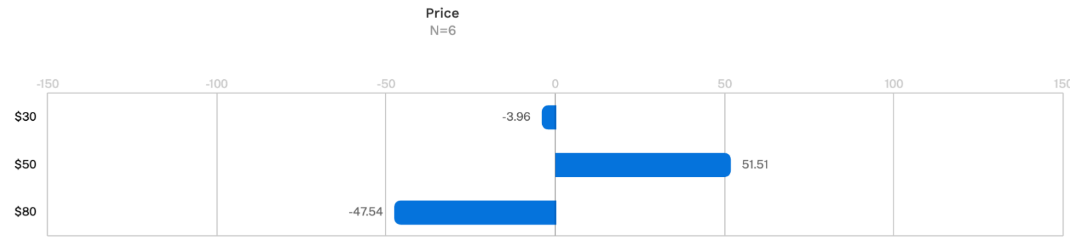
This strategic price gap enables broader market capture while preserving product positioning. It allows us to address distinct user personas without cannibalizing the core offering. Importantly, both versions remain financially viable, with positive NPV projections, and their segmentation ensures the business can scale across mainstream and niche markets simultaneously.

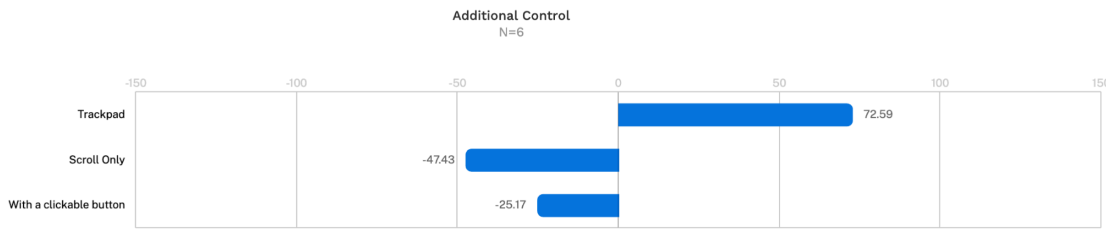
4.3.1.Derived from Conjoint and other observations

The CBC survey results identified “Additional Control” (such as trackpad and gesture input) and “Price” as the two most influential factors in purchasing decisions. These attributes guided the feature–price pairing in our product strategy.

The pricing curve showed that *$50* was the most preferred price point, with a utility score of *+51.5*. Options priced at $80 or higher saw a sharp drop in preference, supporting our decision to reserve the $130 price point for a clearly differentiated premium model. Trackpad-integrated formats scored significantly higher than scroll-only variants, with a utility value of *+72.59*, confirming user willingness to pay more for enhanced control.These findings validate the $50 and $130 price brackets, ensuring each SKU aligns with user expectations while maintaining volume adoption and margin viability.





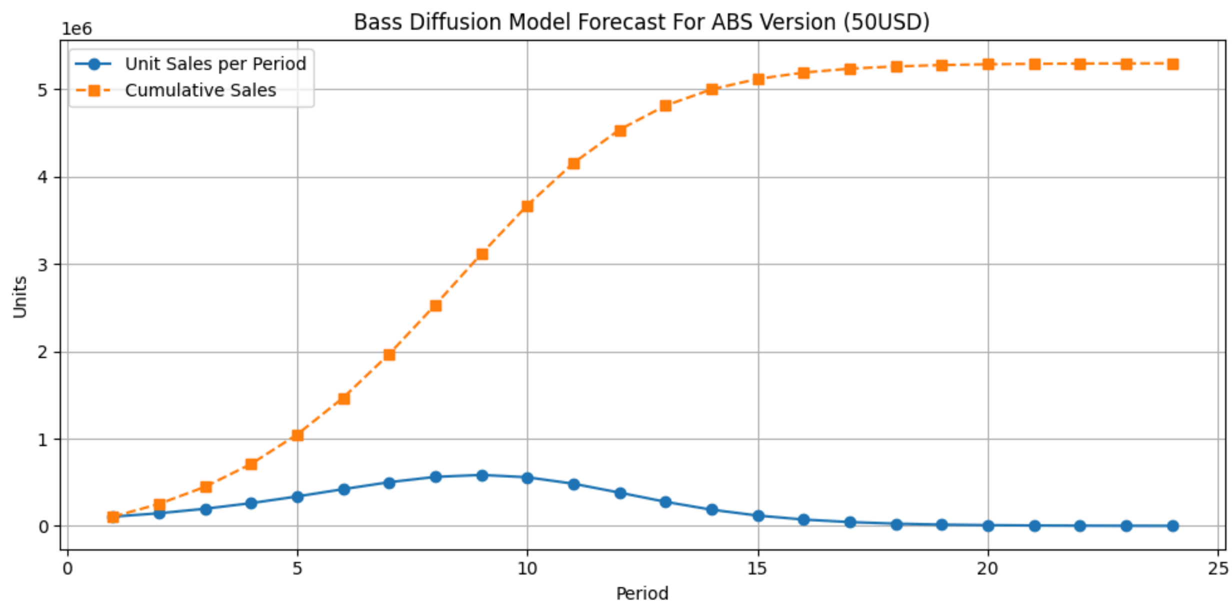


4.4. Bass Model Forecasting to predict product demand

To forecast unit demand over a 24- to 36-month commercialization horizon, we used the Bass Diffusion Model, which predicts product adoption by combining early adoption behavior with peer influence. Each SKU was modeled separately to reflect its unique adoption curve.The ABS version, designed for mass-market appeal, shows a faster adoption rate with earlier peak sales. In contrast, the Aluminum version has a more gradual curve, consistent with premium product adoption patterns.

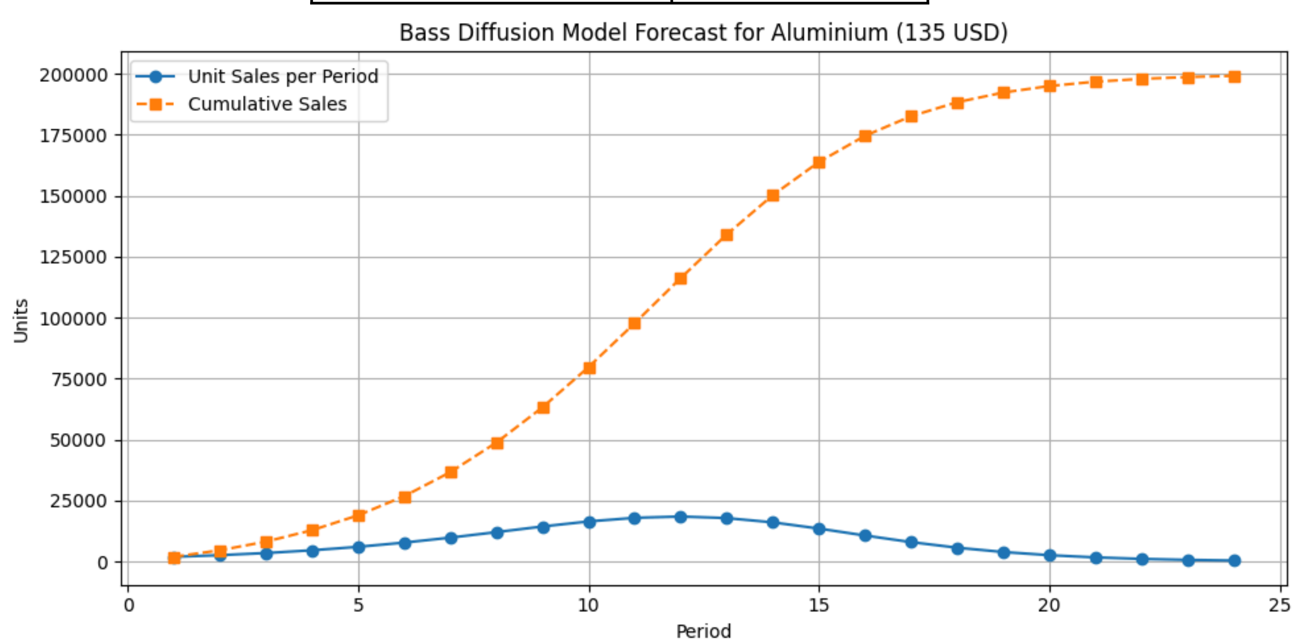
ABS Version Parameters:

Parameter	Value
Market Size (M)	1,000,000 units
Innovation (p)	0.02
Imitation (q)	0.40



Aluminum Version Parameters:

Parameter	Value
Market Size (M)	200,000 units
Innovation (p)	0.01
Imitation (q)	0.35



Model Justification:

The parameter values for p and q were derived from published diffusion models in consumer electronics, specifically Tigert & Farivar (1981), and adjusted to reflect the characteristics of our user segments. The ABS version reflects early demand driven by influencers and gaming communities, while the Aluminum version follows a slower novelty curve typical of premium accessories. This modeling supports decisions on production ramp-up, marketing spend allocation (primarily concentrated between periods 10–22), tooling amortization, and long-term planning for restocking or a second-generation release.

4.5. Production Costs

The Spin Wheel is manufactured in two distinct variants—ABS (injection-molded) and Aluminum (CNC-machined)—each optimized for a unique balance of cost, performance, and user experience.

4.5.1. What manufacturing process will you use?

The ABS version is produced using injection molding, which allows for rapid, high-volume manufacturing with low per-unit cost. This method supports efficient throughput and minimal material waste, making it ideal for large-scale production. It also enables integration of surface textures and coloration directly into the mold, eliminating the need for post-processing.The Aluminum version is manufactured using CNC machining from 6061 aluminum, followed by anodizing for surface durability and aesthetics. This process offers high dimensional precision and superior stiffness, aligning with the expectations of premium-tier users. Though better suited for lower-volume production, it supports high-margin positioning due to its finish quality and perceived value.

4.5.1.1. Ashby charts

The selection of ABS and Aluminum 6061 was guided by material performance plots:

Thermal Conductivity vs. Density

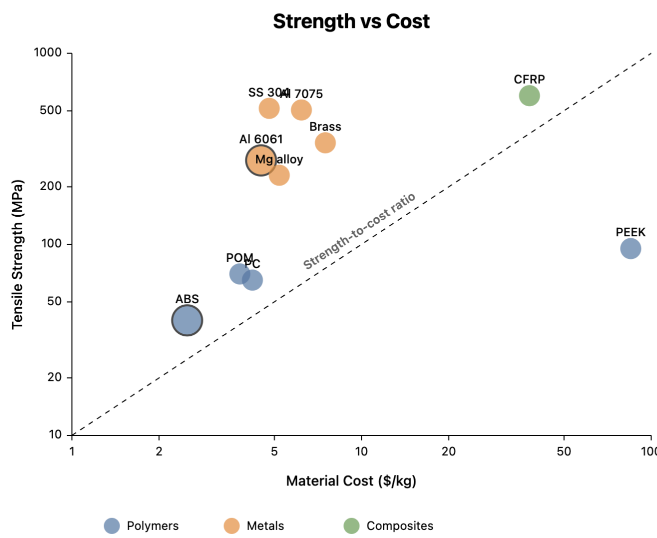
Aluminum alloys provide 10–20× higher thermal conductivity than polymers, supporting cool-touch, high-end feel for the premium variant.

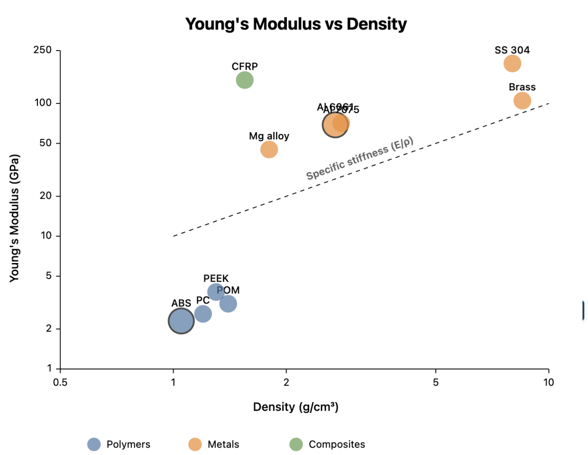
Strength vs. Cost:

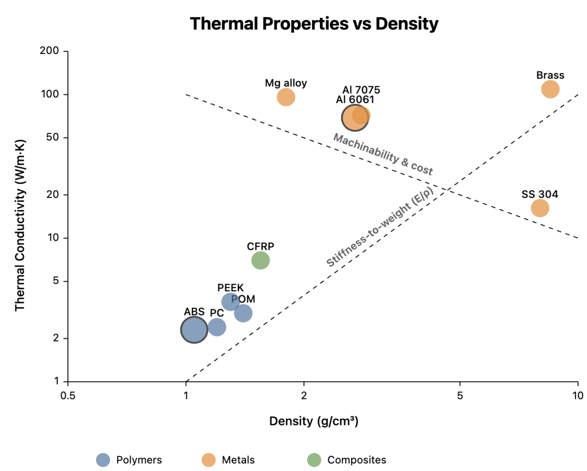
ABS offers solid strength-to-cost performance, while Al 6061 delivers a midpoint in tensile strength at reasonable cost compared to steels or exotic composites.

Young’s Modulus vs. Density:

ABS provides good compliance and weight savings, making it well-suited for portable use and reducing user fatigue during extended sessions. In contrast, aluminum alloys offer high stiffness-to-weight ratios, which enhance the device’s mechanical response and perceived precision—qualities valued in premium input hardware.







4.5.2. Tooling parameters and costs

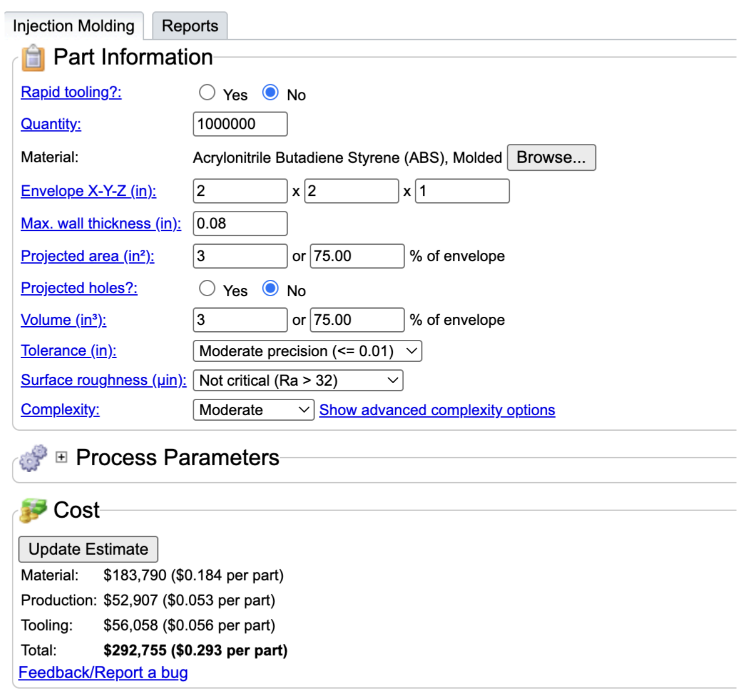
The tooling and ramp-up cost structure for the Spin Wheel reflects the manufacturing process chosen for each version. These non-recurring engineering (NRE) costs are factored into the NPV model and amortized over projected unit volumes.

ABS Version – Injection Molding

Injection molding for the ABS variant involves high upfront tooling costs but results in extremely low per-part production costs at scale. Using DFM analysis and industry-standard cost estimation tools, we established the following:

Parameter	Value
Material	ABS
Mold Cost	\$56,058
Total Production Volume	1,000,000 units
Ramp-Up & Validation	~\$40,000
Total Tooling + Ramp-Up	**~\$100,000 / period**

Injection molding cost breakdown showing \$0.293/part total cost including \$0.056 amortized tooling cost.

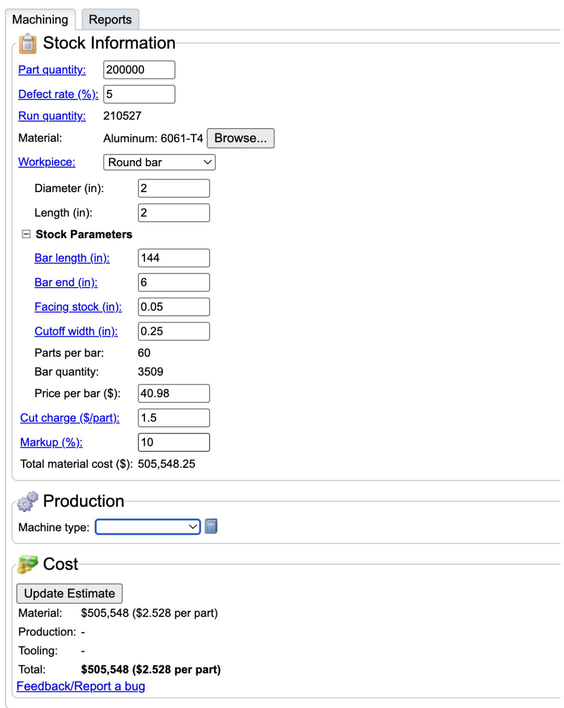


Aluminum Version – CNC Machining

For the aluminum version, we selected 6061-T4 stock, cut from 2" round bar and machined into the final form. While it does not require hard tooling, there are significant setup and fixturing costs, as well as higher material input costs. Based on CNC cost modeling, we defined the following:

Parameter	Value
Material	Aluminum 6061
Total Quantity	200,000 units (including 5% defect margin)
Tooling Setup & Jigs	$10,000
Ramp-Up & Programming	$20,000
Total Tooling + Ramp-Up	**~$30,000 / period**

CNC machining cost output with $2.528/part material cost and detailed stock configuration parameters.



Version	Tooling Cost	Ramp-Up Cost	Total	Amortized Volume	Tooling per Unit
ABS	$56,058	~$40,000	~$100,000	1,000,000 units	~$0.10
Aluminum	$10,000	$20,000	$30,000	200,000 units	~$0.15

This cost structure ensures profitability at both ends of the pricing spectrum, with high-volume amortization for ABS and efficient small-batch setup for Aluminum.

4.6. Cost of Goods Sold

The Cost of Goods Sold (COGS) for the Spin Wheel includes all recurring costs associated with manufacturing each unit—namely raw materials, machining or molding labor, and electronics. The COGS structure supports high scalability for the ABS version and premium margins for the Aluminum version.

4.6.1. Materials, labor, off the shelf components

Electronics (Shared Across ABS and Aluminum Versions):

Component	Estimated Cost Range
Magnetic Encoder	\$2 – \$4
BLDC Motor (Haptic)	\$3 – \$6
Bluetooth MCU (nRF52840)	\$2.50 – \$5
Touchpad	\$9
Assembly + Testing	\$2 – \$4
Total Electronics BOM	**\$18 – \$26**

ABS Version (Injection Molded):

Parameter	Value
Housing Volume	~46.66 cm³
Material	ABS
Material Cost	~\$0.12
Injection Molding (per unit)	\$0.50 – \$1.50
Mechanical COGS (housing)	\$1.50 – \$2.00
Electronics BOM	\$18 – \$26
Total COGS	**\$20 – \$30 (avg. ~\$25)**

Aluminum Version (CNC Machined + Anodized):

Parameter	Value
Housing Volume	46.66 cm^3 (~126 g)
Material	6061 Aluminum
Material Cost	~$0.50 per part
Machining Cost	$25 – $40
Finishing (Anodizing)	$1 – $2
QC + Assembly Prep	$1 – $2
Setup Amortization	$0.50 – $5
Mechanical COGS (housing)	$28 – $49
Electronics BOM	$18 – $26
Total COGS	**$48 – $75 (avg. ~$55)**

4.7. Warranties

To ensure customer satisfaction and support long-term adoption, the Spin Wheel includes a structured warranty policy supported by preliminary mechanical reliability modeling and failure rate estimation.

The two product variants — ABS (injection molded) and Aluminum (CNC-machined) — differ in durability expectations, but both are evaluated under standardized use cycles involving scroll input, rotational twist, and button press.

While formal finite element simulations are still pending (and will be reported in Section 2.6), we developed a warranty strategy based on standard material data, estimated usage forces, and conservative fatigue modeling. This ensures that the warranty terms are backed by realistic assumptions—even in the absence of custom stress analysis.

4.7.1. Weibull distribution around FEA cyclic loading failure prediction

In lieu of custom FEA simulations, we referenced published mechanical properties and handbook data for ABS and Aluminum 6061 to estimate stress thresholds and fatigue life. The loading model assumed scroll and press forces in the range of 2–10 N, which corresponds to typical user input for input devices such as styluses and scroll wheels. The interaction is expected to be free of sliding or impact loading, making it a controlled, repetitive stress environment.

Material properties used in this estimation included a yield strength of ~40 MPa and elastic modulus of ~2,000 MPa for ABS, and ~275 MPa yield strength with ~68,000 MPa modulus for aluminum 6061-T6. Using a conservative loading area of ~466 mm², calculated stress remains well below yield thresholds for both materials under normal use.These values were used to define a Weibull distribution model for cyclic life, with a **shape parameter (β) of 2.0** to represent wear-dominated failure, and a scale **parameter (η) selected to ensure 90% survival** beyond two years of daily use. This distribution serves as the basis for warranty terms and failure risk assumptions, pending verification by detailed FEA analysis.

4.7.2.How will you handle product mishaps?

The Spin Wheel warranty covers mechanical and electrical failures that occur under normal usage conditions. This includes material cracking or deformation, failure of key components such as the magnetic encoder, trackpad, or Bluetooth microcontroller, as well as solder joint or PCB-level faults. The warranty is designed to reflect both the projected durability of the product and the confidence in its manufacturing quality.

Warranty Plan:

For the first 6 months, customers are eligible for a full replacement or refund with no conditions. From 6 to 24 months, replacements are offered upon verification of failure, either through return, user-submitted evidence, or in the future, via firmware-based diagnostics. After the warranty period, users may be offered discounted upgrades or repair services. Future firmware updates may also include error logging or usage-hour tracking via Bluetooth to assist in validating warranty claims.

5. Legal Requirements

5.1. Safety & Environmental Regulations

The aluminum version can be used as a weapon with an outer shell mass of 126 grams. Both versions of the Spin Wheel use electrical components and contain lithium batteries, therefore proper disposal of the device is required.

5.2. Potential Liability Issues

The Spin Wheel is designed to be completely wireless, which means if not secured properly can be vulnerable to eavesdropping or malice input injection. Additionally another factor could be the ergonomics of the design. Although the intention behind the SpinWheel is to also decrease fatigue and prevent carpal tunnel, there could be other physical side effects from prolonged use.

5.2.1. Prediction of Misuse Cases

Due to the point of connection, connecting the SpinWheel can open another entrance for computer hackers and other mischievous individuals to connect to your device.
Also because the SpinWheel is customizable, if the user opens the source code, they can reprogram the SpinWheel to do another function that it was not designed for, other than scrolling.

5.2.1.1. Failure Mode and Effect Analysis

Component	Failure Mode	Effect of Failure	Cause	Severity (S)	Occurrence (O)	Detection (D)	RPN (S×O×D)
Motor	Jerky or no scrolling	Navigation is difficult	Sensor misalignment, dirt buildup	6	5	5	150
Battery System	No power or short usage time	Mouse stops working unexpectedly	Battery degradation, poor contact	7	5	5	175
Wireless Connection	Intermittent or no connection	Lag, dropped input, or complete disconnect	Signal interference, firmware bug	9	4	4	144
Housing/ Case	Cracking or loose components	Poor user experience; potential internal damage	Dropping, poor material, weak fasteners	5	5	6	150
Touch Surface	Gestures not recognized	Reduced functionality	Firmware glitch, user error	6	3	6	108

5.3. Intellectual Property Considerations?

The SpinWheel has similar functionality to computer mice and other devices. Although, the device itself is unique, in terms of intellectual property, the add ons and other features must be carefully created to not overlap with other devices.

5.3.1.Patent Landscape

The landscape includes several key areas, including tracking technology, ergonomic design, wireless communication, and user input enhancements. Some more features spanning the landscape include touch-sensitive surfaces, gesture recognition, and gyroscopic controls, particularly prominent in products from Apple, Logitech, and Razer. Overall each individual component and aspect has variations patented which need to be worked around.

5.3.2.Pursue Utility, Design patents? Why?

The SpinWheel is able to pursue both a utility and a design patent. The SpinWheel brings a new design to the common scroll wheel which requires a patent. In Addition, it also brings new utility including new design characteristics that aren't commonly found in like devices.

5.3.3.Trade secrets? Why?

Although the device being sold can be taken apart, the SpinWheel may contain certain trade secrets. The materials used are common inorder to reduce costs but the code itself which is used to translate the radial movement of the SpinWheel to lateral movement within the computer can be considered a trade secret. Without it, the device wouldn't be able to function and the code is unique and specific to the design.

5.3.4.Trademark? Describe

The Logo and name of the device can be trademarked. As both revolve specifically to this device and are unique to describe not only the functionality but also the brand

5.3.4.1. Team name and logo

TeamName: SpinWheel

5.3.4.2. Other trademark opportunities?

Because the overall shape of the device is unique, and will be something recognizable, that is room for another trademark.

6. Environmental Targets

The Spin Wheel project considers environmental sustainability during both its production phase and end-of-life by making deliberate choices in materials, manufacturing, and disassembly potential.

6.1. How will the products reduce environmental impact on production?

The Spin Wheel's two SKUs allow us to align material choice with manufacturing footprint:

ABS Version (Injection Molded):

The ABS version of the Spin Wheel is designed with material efficiency in mind, using minimal wall thickness and a compact volume of approximately *46.6* cm^3. This reduces the amount of ABS resin required per unit and lowers the overall energy input during molding. Injection molding further supports waste reduction through cycle-optimized tooling, which minimizes offcuts and improves part consistency.

Once tooling is established, the energy demand per unit is significantly lower compared to subtractive manufacturing methods. The process is highly scalable, and its compatibility with outsourced or regional production makes it possible to reduce emissions related to long-distance shipping, depending on localized demand.

Aluminum Version (CNC Machined):

The aluminum version uses round-bar stock optimized for 2” billet cuts, which reduces material scrap during CNC machining. By sourcing 6061-T4 aluminum from recycled suppliers, the process achieves up to 95% energy savings compared to virgin material. The increased durability of the aluminum housing also extends product lifespan, lowering replacement frequency and minimizing the long-term environmental impact.

6.2. How will the products reduce environmental impact upon end of life?

Both versions of the Spin Wheel were designed for ease of disassembly and material recovery. The housings use mechanical fasteners rather than adhesives, allowing components like the battery and PCB to be separated for targeted recycling. The ABS shell consists of a single polymer with no overmolding, improving recyclability, while the aluminum version is made entirely from 6061 alloy, which can be processed through standard scrap channels.

Off-the-shelf electronic components further simplify e-waste handling. In the future, a refurbishment or reuse program may be introduced, particularly for the aluminum variant, which is mechanically robust enough for resale or re-skinning.

7. Sources

7.1. Bibliography

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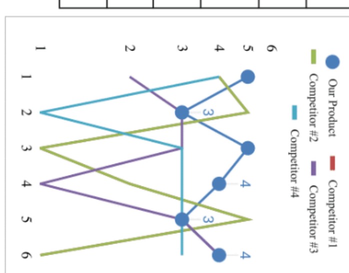
7.2. Appendices

A. HOQ

Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	1: Magnetic Encoder (AS5600)	2: nRF52840 Microcontroller	3: BLDC motor mounted scrolling	4: 400 mAh Battery	5: Touch Trackpad (Circular)	Our Product: SPIN WHEEL	Competitor #1: Kensington scroll Ball	Competitor #2: Dell Mouse	Competitor #3: 3dConexion CAD mous	Competitor #4: *Microsoft Surface Dial*
					Direction of Improvement	▲	▲	◇	◇						
1		24%	10	9	SCROLLING (SMOOTH, PRECISE)	●		▽			5	4	4	2	4
2		12%	5	9	CROSS PLATFORM USE		●	●			3	5	5	3	1
3		24%	10	9	CUSTIMISABLE SCROLL FEEL (INDENTS, SENSITIVITY)	●	○	●			5	1	1	3	3
4		17%	7	9	DURABILITY	●			▽		4	2	2	1	3
5		10%	4	9	BATTERY LIFE		○		●		3	5	5	3	3
6		14%	6	9	ADDITIONAL CONTROL		○			●	4	1	1	4	3

Column #	1	2	3	4	5
Max Relationship	9	9	9	9	9
Technical Importance Rating	8.57142	250	5.23809	2.38095	8.57142
Relative Weight	41%	18%	25%	7%	9%
Weight Chart					
Our Product : SPIN WHEEL	5	5	5	5	5
Competitor #1: *Kensington Scroll Ball*	1	-	-	-	-
Competitor #2: *Dell Mouse*	2	-	-	-	4
Competitor #3: 3dConexion CAD mouse	1	3	1	2	1
Competitor #4: Microsoft Surface Dial	3	4	3	4	4

Customer Competitive Assesment



Row #

B. Bass Model Functions (Python)

```python
#@title BASS MODEL FUCNTION

import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

# Bass Model Function
def bass_diffusion_model(p, q, M, periods):
   S = np.zeros(periods)  # sales per period
   Y = np.zeros(periods)  # cumulative sales

   for t in range(periods):
       if t == 0:
           S[t] = p * M
       else:
           S[t] = (p + q * (Y[t - 1] / M)) * (M - Y[t - 1])
       Y[t] = Y[t - 1] + S[t] if t > 0 else S[t]

   return S, Y
```

```python
# ABS VERSION
# __________
# Parameters
p = 0.02  # Innovation coefficient
q = 0.4   # Imitation coefficient
M = 1000000  # Total market potential
periods = 24  # Number of periods

# Generate Forecast
sales, cumulative_sales = bass_diffusion_model(p, q, M, periods)

# Create DataFrame
df = pd.DataFrame({
   'Period': np.arange(1, periods + 1),
   'Unit Sales': np.round(sales).astype(int),
   'Cumulative Sales': np.round(cumulative_sales).astype(int)
})

# Display Table
print(df)

# Plot Forecast
plt.figure(figsize=(10, 5))
plt.plot(df['Period'], df['Unit Sales'], marker='o', label='Unit Sales per Period')
plt.plot(df['Period'], df['Cumulative Sales'], marker='s', linestyle='--',
```

```python
label='Cumulative Sales')
plt.title('Bass Diffusion Model Forecast For ABS Version (50USD)')
plt.xlabel('Period')
plt.ylabel('Units')
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```

```python
# ALUMINIUM VERSION
# ________________
# Parameters
p = 0.01  # Innovation coefficient
q = 0.35   # Imitation coefficient
M = 200000  # Total market potential
periods = 24  # Number of periods

# Generate Forecast
sales, cumulative_sales = bass_diffusion_model(p, q, M, periods)

# Create DataFrame
df = pd.DataFrame({
   'Period': np.arange(1, periods + 1),
   'Unit Sales': np.round(sales).astype(int),
   'Cumulative Sales': np.round(cumulative_sales).astype(int)
})

# Display Table
print(df)

# Plot Forecast
plt.figure(figsize=(10, 5))
plt.plot(df['Period'], df['Unit Sales'], marker='o', label='Unit Sales per Period')
plt.plot(df['Period'], df['Cumulative Sales'], marker='s', linestyle='--', label='Cumulative
Sales')
plt.title('Bass Diffusion Model Forecast for Aluminium (135 USD)')
plt.xlabel('Period')
plt.ylabel('Units')
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
```

C. Product Gallery