Dialogic STEM Journal

Volume 1, Issue 1, 2026 available at www.dapresses.com

Article

Design, Prototyping and Testing of Mechatronic Spinner for Domian-Based Systems Thinking for Co-creativity, Co-analysis and Co-reflection

Chukwuma Ogbonnaya[1]* and Chagary Ranjan[1]

[1]Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Epinal Way, Loughborough LE11 3TU.
*Correspondence: c.ogbonnaya@lboro.ac.uk; Tel.: +447438503799.

Abstract: This paper presented the design, development and rapid prototyping of a novel heptagonal mechatronic spinner for practicing and gamification of "Domain–Based Systems and Systematic thinking". The spinner is intended to facilitate teaching, learning, brainstorming, storytelling, systematic thinking, co-creative, co-analysis, leisure and game activities. To realise the Mechatronic Spinner including seven domains (i.e. Objective, Place, People, Process, Time, Reason and Specific domains) steps including ideas generation, hand sketching, detailed engineering design, design optimisations, circuit design, coding, prototyping and testing were implemented leveraging Lean and Agile Design and Rapid Prototyping with additive manufacturing. The mechatronic system realised, expectedly, generated randomness at each spin, which makes it suitable for application for cognitive activities. A case of how the spinner can be used for teaching and learning probability and statistics based on the numerical feature was instantiated. This device offers a wide range of opportunities to practice creative and analytical thinking activities such as domain-based brainstorming, ideas generation and problem-solving.

Keywords: Creativity; Questelligence; Domain-based Thinking; Systems Thinking; Metacognition, Lean and Agile Methods; Additive Manufacturing; Mechatronics.

Academic Editor: Dr Chukwuma Ogbonnaya

Received: xx/xx/yyyy Revised: xx/xx/yyyy Accepted: xx/xx/yyyy Published: xx/xx/yyyy

Citation: To be added by editorial staff during production.

1. Introduction

Ogbonnaya [1] proposed thinking as a deterministic mathematical process of permutations and combinations based on sets of items from the domains of thoughts. He explained that these items can be cognitively and randomly selected from seven Questelligence domains (i.e. Objective, Place, People, Process, Time, Reason and Specific domains) which human beings have evolved over the centuries. He hypothesised that a systematic application of the Questelliegence framework could improve creativity (where items of thought are synthesised to create a whole meaning) [2], analytical thinking (where a whole meaning is deconstructed into items for better understanding) and reflective thinking (where both analytical and creative thinking are simultaneously applied) skills. Thinking, although abstract in form, can be applied for brainstorming, creation of new solutions and analysis of existing solutions, reflective thinking, systems thinking, mathematical thinking, etc. This abstract nature makes thinking a difficult task for many people and the overarching goal of the Questelligence theory is to concretise thinking process by providing a physical device that people can interact with to enhance their domain-based thinking skills. This motivates the design and development of the proposed Mechatronic Spinner leveraging Lean and Agile Design and Rapid Prototyping (LADRP) methodology with additive manufacturing process. The concretisation of the domain-based thinking follows the same principle of gamification of teaching and learning. Studies have shown that gamification is very beneficial for teaching and learning because physical objects in a gamified environment act as psychological anchor tools for motivation of learners [3,4]. In this study, gamification of the learning of statistics and probability was used as a case study to instantiate the practical application of the Mechatronic Spinner.

The Mechatronic Spinner device is described as a system in this paper because it represents a physical configuration of components that accepts inputs, harmoniously transforms the inputs into outputs based on certain rules and algorithms [1]. Systems thinking is an approach to thinking in which the interactions of the components of a system are considered to visualise how they affect the overall behaviour of a system or how the overall behaviour of a system affects the interactions of subsystems, components and parts [5]. Here, there are two dimensions of application of systems thinking and systems theory. First, the Mechatronic spinner under development is for practicing “domain-based system and systematic thinking” [1]. Second, systems theory and systems thinking were applied to understand the interactions of the components of the spinner. Ogbonnaya [1] proposed a heptagonal shape including the seven Questelligence domains as shown in (Figure 1). Contextually, “Questelligence” was coined from “questions and intelligence”, to suggest that asking questions based on the Questelligence framework can improve intelligence. Detailed theoretical, epistemological and ontological arguments to support the Questelligence framework can be found in two major books by Ogbonnaya [1,6].

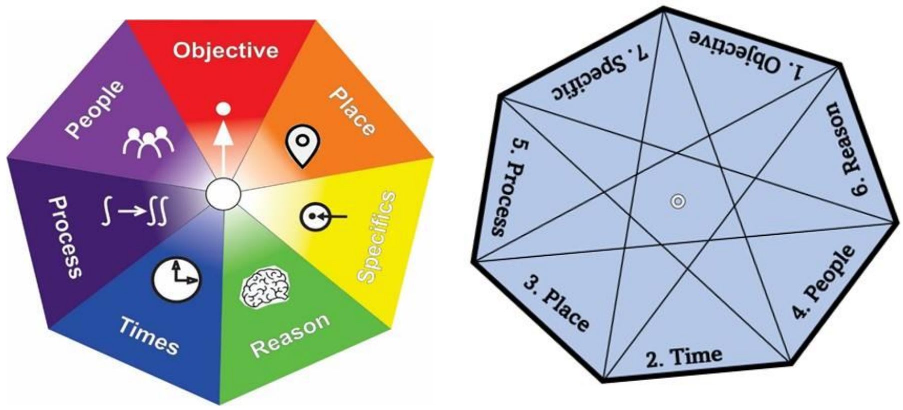


Figure 1: The Questelligence domains [1]

Contextually, based on the Questelligence theory and the proposed theory of thinking, ‘Objective or Object domain’ focuses on the purpose or concept or physical object on which the action of thinking is focussed on. ‘People domain’ identifies the “human elements in the thoughts” and it may include people, states, organisations or fictional persons. The ‘Place domain’ emphasises the “space which can be positional on the body of objects, geographical, virtual or abstract”. ‘Process domain’ represents the notion of change or transformation from one form to another or from one state to another. ‘Reason domain’ uses the “permutations and combinations of different domains to create logic and patterns”. The ‘Time domain’ domain provides the notion of past, present and future while the ‘Specific domain’ highlights a specific item from “several items from other domains”. The fundamental proposition is that items are selected from these domains based on mathematical processes of permutation, combination, set theory and probability to analyse, create and share meanings.

As a pedagogical approach, gamification of learning makes teaching and learning activities more structured and intended learning outcomes can be embedded in games [7,8]. Evidence from research agree that gamification of learning increase motivation, positive attitude in individuals and makes learning tasks more engaging – thereby making learning more effective and a happy experience [9–12]. For instance, high levels of dopamine were found in a situation involving uncertainty [13]. Skok [14] stated that randomness is a “powerful tool of releasing positive emotions” and increasing attachment to a game. Ozcelik, Cagiltay and Ozcelik [15] divided 140 computer engineering students into two groups during an activity – one to undertake certain task and the other to undertake uncertain task. They concluded that the effect of gamified uncertainty in the group with uncertainty in their learning task caused them to perform better than the group with certainty in their task. This was supported by Howards [16] who discovered that there was an increase in electrodermal activity when participants in research were asked questions including uncertainty. An increase in electrodermal activity means that the individual is emotionally or physically stimulated. Research suggests that individuals on the extreme ends of neurodivergent scale find it hard to solve problems due to cognitive inactivity or lack of concentration on the question [17]. Meanwhile, the effectiveness of computational thinking methods can be improved by using frameworks or models [18]. The Mechatronic Spinner will serve as a pedagogical gamification tool or tool for structured systems thinking within the Questelligence framework to facilitate cognitive activities in people at the lower end of neurodivergent scale or concentration of thoughts a higher end of neurodivergent scale. Of course, people within normal neurodivergent scale will find it useful for various cognitive processes whilst the computational feature will provide insights for understanding the mind of artificial minds such as artificial intelligence models.

The overall aim of this research was to design, develop, optimize, manufacture and test a mechatronic-based spinner cable of generating randomness of the seven Questelligence domains. LADRP using additive manufacturing was employed to realise the prototype as quickly as possible at a low cost. To achieve this overarching aim in a systematic way, the following objectives were pursued:

i. Generate conceptual designs of the game spinner using hand sketching.
ii. Down select the best design using a Pugh Matrix.
iii. Create 2D and 3D engineering drawings of the selected design using NX software.
iv. Use a Morphology matrix to select materials and processes.
v. Perform Failure mode and effect analysis (FMEA) to improve the functionality of the system.
vi. Optimise critical components using finite elements analysis (FEA) using NX software.
vii. Manufacture the components using additive manufacturing (AM).
viii. Assemble and test the Mechatronic Spinner System.
ix. Demonstrate the Mechatronic Spinner System in gamifying the learning of statistics and probability [19].
x. Discuss the applications of domain-based thinking for creative, analytic and reflective thinking.

The originality and potential impact of Mechatronic Spinner System for practicing and gamification of theory of mind, systems theory, systems thinking and systematic thinking proposed by Ogbonnaya [1] makes this paper a foundational academic article. This physical device enables metacognitive framework formal and informal activities, including individual and group activities, to be developed based on the Mechatronic Spinner System based on needs. The contribution of the Mechatronic Spinner System to pedagogy and research is that it will provide new opportunities for investigations into cognitive activities based on the proposed structured Questelligence framework and domain-based thinking. The Mechatronic Spinner will be valuable in teaching and learning [20], including reproducing it as STEM activity or using it to learn mechatronic systems architecture. The outline of the paper is as follows. The next section presents the research methodology used to realise the research objectives. Section 3 presents the outcome of testing and validation of the Mechatronic Spinner and design optimisation. Section 4 shows how the software and the hardware were integrated. Section 5 describes the additive manufacturing process for prototyping of the device. Section 6 presents a case study of generating data which can be used for probability and statistics. Section 7 presents the target costing for the device. Section 8 explores the application of domain-based systems thinking for creativity, analysis and reflection while Section 9 concluded the study.

2. Research Methodology

2.1 Product Design based on Design Thinking

LADRP methodology was implemented to realise the Mechatronic Spinner System using the Stanford University Design Thinking process [21,22]. These methodologies are suitable for novel creative problem-solving [22]. LADRP provided an overall framework to realise a quality, cost-effective Mechatronic Spinner System with the shortest lead time. The Design Thinking process offers a step-by-step process of realising the physical device. It involves 5 steps: Empathize, Define, Ideate, Prototype and Test [22]. The Empathise phase was based on the "need to concretise domain-based systems and systematic thinking given that thinking is abstract". The Define stage specified the challenge of engaging in thinking without having a physical object to interact with, focus on or remember to enhance metacognitive framework for systems thinking.

The Ideate phase involves specifying the Mechatronic Spinner System as a mechatronic system, and identifying systems requirements such as ease of disassembly, aesthetics and control system. Pugh and Morphology matrices were used to create different design options. The Prototype stage was "intended to answer questions that get you closer to your final solution". At this stage CAD designs were created and tweaked with FEA and FMEA leading to the final design option. Due to the incorporation of an electronic aspect, this mode also includes the iterative prototyping of the circuit within the spinner. The Test phase facilitated feedback from the individuals involved in the empathize mode and those involved in the case study.

The Mechatronic Spinner System was designed to include mechanical, electrical and control systems [23]. The dependencies of the components of the system were considered at the beginning of the design process. The mechatronic system design process includes modelling and simulation, prototyping and deployment [24]. The RS Design Park website was used to select the DC motor for the spinner due to their easy installation, quick start/stop and very common in small appliances [25]. Brushless motors were used because they are more efficient and quieter, although they can be slightly costlier than AC motors.

2.2 Concept Generation and Down Selection

A Product Design Specification (PDS) was created to identify the requirements for the Game Spinner System as presented in Table 1. The key identified limiting factors were cost, manufacturing method, material and lead time. These will guide the rapid prototyping process[26]

Table 1: Product Design Specification

Attribute	Requirements
Performance	Must spin the gameplate to a random seventh every time.
Cost	Max £100 available.
Asthetics	Fun and eye catching for users.
manufacture	3D Printed.
Materials	Limited to available materials for 3D printers.
Size	A practical size to use as a teaching tool. Must be able to fit on a print bed.
Saftey	No sharp corners. Electronic compoennets connected correctly and university standards met.
Life Cycle	Should last a minimum of one year.
Maintanance	Should be able to access the inside eletronics and plate.
Practical	Can be stored away efficiently and passed around a class.

Pugh matrix in Table 2 was used to analyse how each proposed design component interfaces to create the Game Spinner System. Three different aspects of the design were considered: the game plate, the outward casing and the motor transmission. The sections were rated from 1- 3, where the lower the total number results a better option. The heptagonal design was selected in the end after the cuboidal design posed new constraints, and the transmission was to be positioned vertically to make 90 degrees angle with the spinner plate.

Table 2: Pugh Matrix for the Game Spinner System.

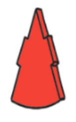
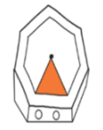
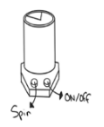
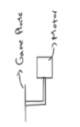
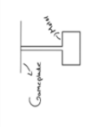
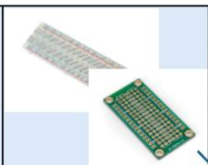
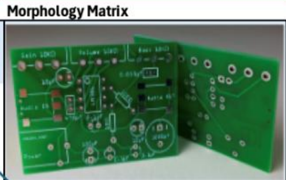
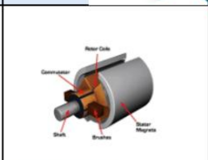
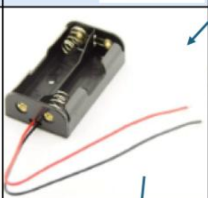
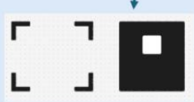
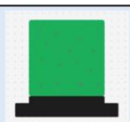
Pugh Matrix							
Critical Qualities							
1. Ease of assembly and disassembly	1	2	3	2	1	2	1
2. Ease of integration of mechatronics components	1	2	2	3	1	2	1
3. Sustainability	2	1	1	3	2	2	1
4. Astehtics	1	2	1	2	3	1	1
5. Practicality	2	1	2	3	1	2	1
6. Ease of Production	2	1	2	3	1	2	1
7. Cost	2	1	2	3	1	2	1
Total	11	10	13	19	10	13	7
For Game Plate:							
Concept 1	3D Printed indicual 1/7's that slot toegther. Could etch on both sides for different game plate assemblies.						
Concept 2	Lazer Etched disc with etched symbols on top						
For overall design:							
Concept 3	In heptagonal shape for modularity						
Concept 4	Cyclinderical shape on a base						
Concept 5	Box shape						
For Motor transmission:							
Concept 6	90° movement transmission						
Concept 7	Straight upwards transmission						

Table 3: Morphology Matrix for the Mechatronic Spinner System.

Morphology Matrix			
Ciriuit Board			
Motor			
Switch			
Power			
Proposal for circuit Fitting			

The mechatronic system was to be designed to integrate with the overall system architecture and mechanical system. Morphology matrix [27] was used to explore the type of components to be used to engineer the Mechatronic Spinner System. The arrow in Table 3 shows the components selected for the electronic subsystem of the Spinner Game System. The circuit was decided as a prototype circuit using a breadboard as opposed to designing a PCB to connect the Brushless DC motor and battery, on/off button and a push button for the spin button. An LED was also ideal to signify the circuit being on. Using battery pack was deliberately chosen to enable the device to function as a portable mobile device.

3. Design and Optimisation of the Mechatronic Spinner Structure

Based on the outcome of the Pugh Matrix, the structure in Figure 2 was proposed to house the mechanical, electronic subsystems and peripheral components such as button, LED and spin button. Upfront, because the Design Thinking process involved getting feedback from the end-users as the design is being iterated, the final design used heptagonal design to enhance the aesthetics of the Mechatronic Spinner System. However, it is important to show how the design evolved and the optimisation efforts that were implemented to realise the research objectives.

To find potential failure areas, FMEA [28] was done to further optimise the design. A failure mode and effect analysis were conducted to identity failure modes that could pose operational risks. The FMEA outcomes presented in Table 4 and 5 show the potential causes of the failures and quantification of the risks of failure based on the likelihood of occurrence, detectability and severity of failure to generate the risk priority numbers.

The slotting area is designated for breadboards and Arduino. It is plausible that the platform may fail due to loads. To investigate the reliability of the platform, FEA as an iterative tool [29] was conducted on the platform as shown in Figure 2. The 2D mesh was subjected to point load of 0.3 N to represent the mass DC motor at 30 g. The highest possible deflection was 0.0069 mm, which was insignificant. This finding points to the possibility of reducing the thickness to safe materials and the use of smaller surface area for the platform.

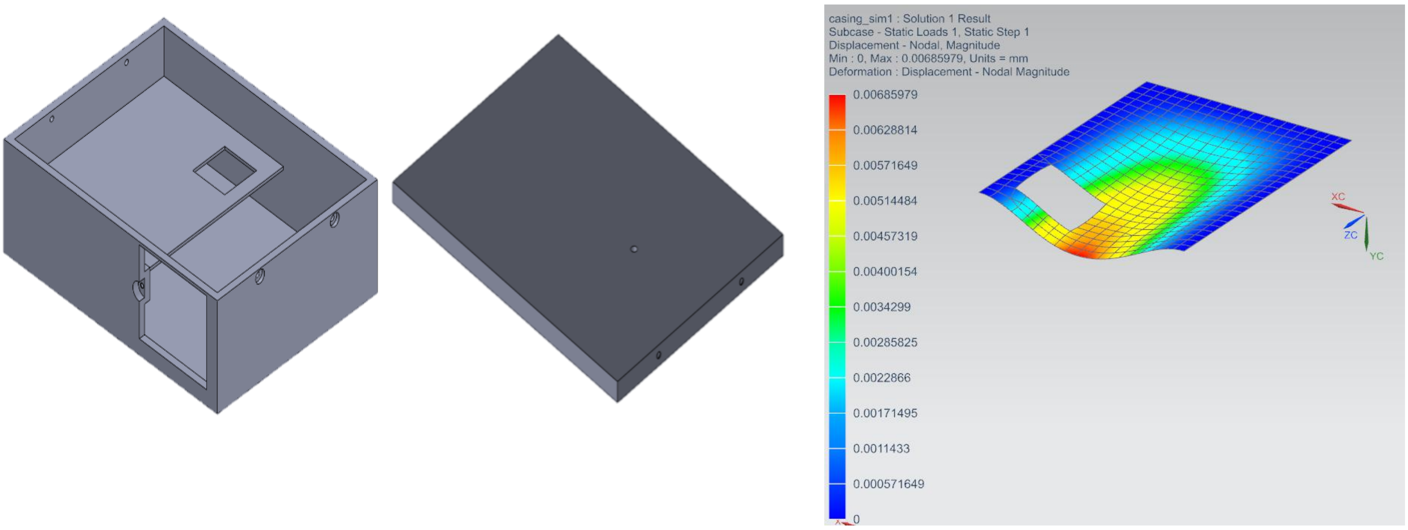


Figure 2: Initial design of the Mechatronic Spinner System Structure (left) and FEA simulation of the platform (right).

Table 4: Modes of failures, causes and effects.

Steps in the Process	Failure Mode	Failure Causes	Failure Effects
Putting the separate components together	Sliding fits wear out	Constant openning and closing of case	Case is no longer an effective lid and will because an inconvinience for usage.
Trying to spin the spinner	Motor Failing	Constant usuage of spinner - casuing life to deteriorate	The Spinner will not work as inetnded if motor can not spin.
	The breadboard disconnects	Wires fall out of breadboard	The circuit will no longer work.
	Gameplate falls down motor	Interferance fit for gameplate fails	The Spinner will no longer spin smoothly.
	Gameplate can not spin despite presseing the button	Friction due to plate touching the motor face	The gameplate will no longer be able to spin.
Using the buttons for the spinner	Press fit for buttons and LED failing	Too much force applied to the buttons casing the press fits to wear	The buttons will end up inside the case - unable to be reached by user.

Table 5: Quantification of the Risk Priority Numbers.

Likelihood of Occurrence (1-10)	Likelihood of Detection (1-10)	Severity (1-10)	Risk Profile Number (RPN)	Actions to Reduce Occurrence of Failure
5	7	5	175	Removeable rivets are added to further hold the parts together allowing for a more secure fit and stil allowing acess to electronics.
4	10	7	280	Brushless DC motors will be used to extend the life of it and a life estimation can be made on when a replacement would be needed.
6	6	7	252	Breadboard is only used for prototype circuits. Eventually a PCB will be desinged.
5	8	6	240	The press fits are reinforced by glue from underneath within the case.
6	6	8	288	Lubrication was applied to face of the motor to counteract the friction force.
3	10	7	210	The press fits are reinforced by glue from underneath within the case.

The final design was informed by the risks associated with assembly and disassembly, acceptability due to aesthetics and the frictional force that will reduce the efficiency if the system is not properly integrated. The Mechatronic Spinner System structure was redesigned with the heptagonal form in Figure 3. It is important to note that the heptagonal design was initially produced using Additive manufacturing and assembled. Additional insights from the initial testing were used to improve design thereby creating a responsive design and development process at a low cost.

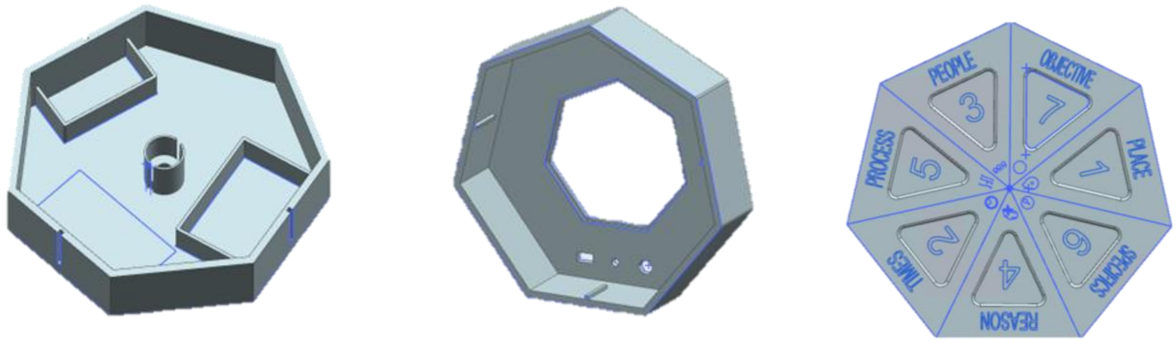


Figure 3: Final design of the Game Spinner System Structure

4. Software Integration

Figure 4 shows the algorithm of the Mechatronic Spinner System. When the circuit is switched on, and the spin button is pressed, a signal is sent to the Arduino to generate a random number of spins. The electronic circuit in Figure 5 was modelled using Tinker CAD [25]. The flip switch controls the LED so that it can indicate when current if flowing through the circuit from a 9 V battery, although only 5 V was eventually used. The push button controls the motor. Arduino coding [30] and circuit building tool and ChatGPT were useful in integrating the components of the systems to generate a random time between 5 and 10 seconds [31].

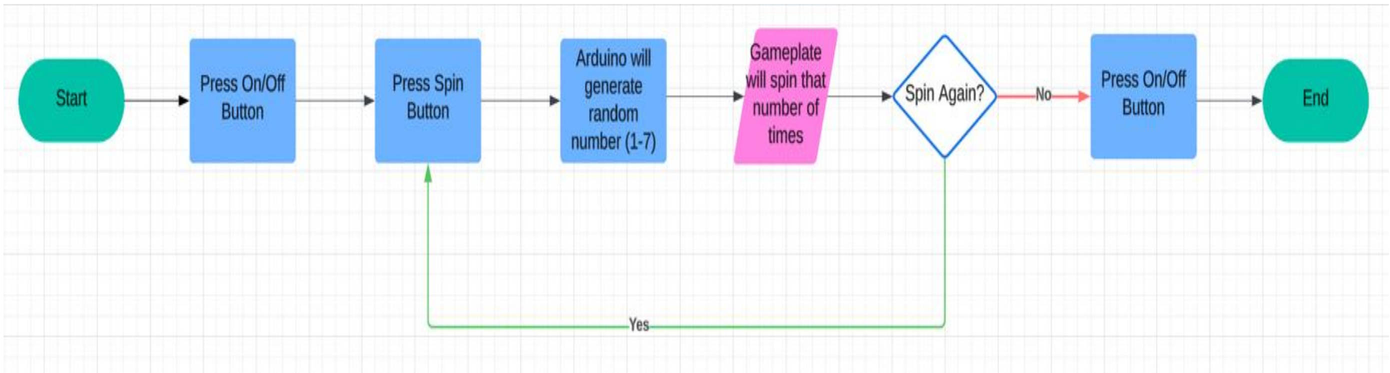


Figure 4: Flowchart of the Algorithm of the Game Spinner System

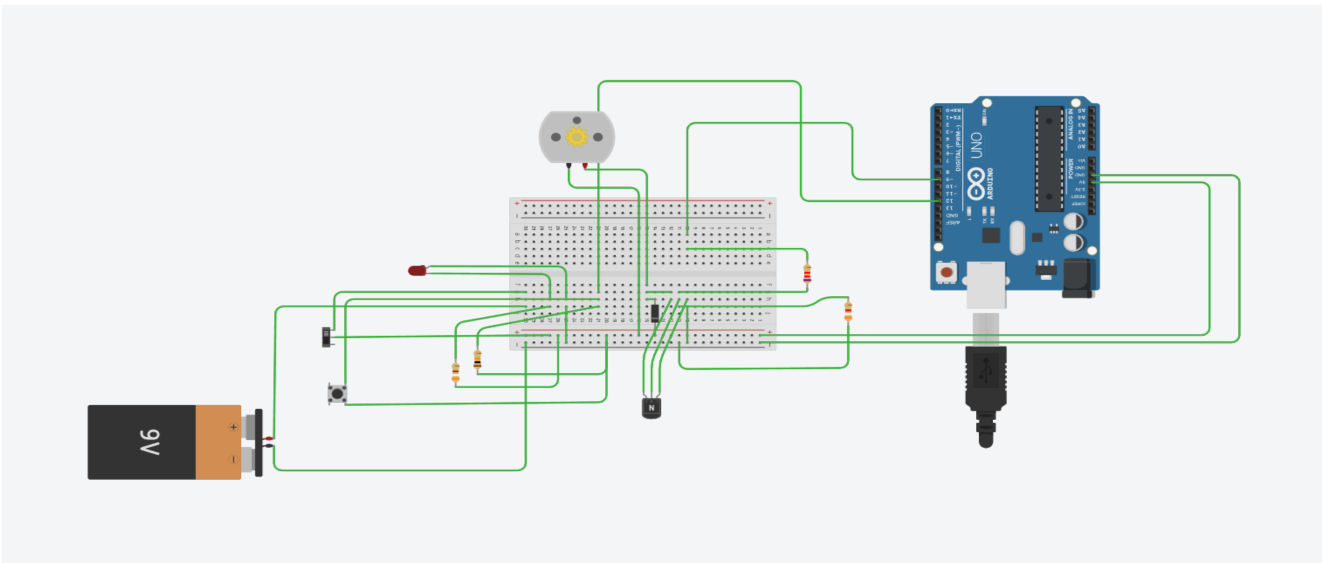


Figure 5: Modelling of the electronic subsystem of the Mechatronic Spinner System

5. Additive Manufacturing, Assembly and Testing

The 3D model of the structure was produced using Additive manufacturing [32,33]. This offered a benefit of complexity for free because the use of traditional manufacturing process would have proved costly and time-consuming. The components purchased from the suppliers and the subsystems were assembled to create functioning Mechatronic Spinner System in Figure 6. The testing of the system was implemented as a case study on the application of the Mechatronic Spinner System for teaching and learning statistics and probability. Mass production using injection moulding can be considered. Improving the aesthetics including colour of the casing may motivate students to use it based on previous findings leading to greater engagement and motivation [34–36].

Figure 6: The image of the Mechatronic Spinner System.

6. Case Study on the use of Game Spinner System for Statistics and Probability.

This case study tests for randomness of the outcomes generated by the Mechatronic Spinner System. Initially, the researchers spun the spinner 200 times and tabulated the outcomes. The Number[frequency] are presented as follows. Side 1[1 time]; Side 2[20 times]; Side 3[20 times]; Side 4[57 times]; Side 5[52 times]; Side 6[10 times] and Side 7[40 times]. Chi-Square goodness of fit test was used to evaluate the fairness of the spinner [37]. The null hypothesis of the test was that the Mechatronic Spinner System does not generate significantly random numbers between 1 and 7. The alternative hypothesis was that the Mechatronic Spinner System generates significantly random numbers between 1 and 7. The level of significance was set at 0.05. It was assumed that each spin was independent of each other to satisfy the requirements of the Chi-Square test. Supposing that the spinner was fair, the expected frequency can be calculated using equation 1.

$$Expected\ Frequency = E = n \times p \quad (1)$$

Thus, $E = 200 \times \frac{1}{7} \approx 28.57$

$Where\ p = probability\ of\ each\ side = \frac{1}{7}\ \ and\ n = no.of\ spins = 200.$

The Chi-Square test statistic can be calculated using equation 2.

$$x^2 = \Sigma \frac{(O - E)^2}{E} \quad (2)$$

$Where\ O = observed\ frequency\ and\ \ E = expected\ frequency$

Table 6: Calculation of the Chi-Square Test Statistic

$\boldsymbol{O}$	$\boldsymbol{E}$	$\boldsymbol{O - E}$	$(\boldsymbol{O - E})^2$	$\frac{(\boldsymbol{O - E})^2}{\boldsymbol{E}}$
1	28.57	-27.57	760.1049	26.6050
20	28.57	-8.57	73.4449	2.5707
20	28.57	-8.57	73.4449	2.5707
57	28.57	28.43	808.2649	28.2907
52	28.57	23.43	548.9649	19.2147
10	28.57	-18.57	344.8449	12.0702
40	28.57	11.43	130.6449	4.5728
Total				$x^2 = 95.8948$

The degrees of freedom (df) for the test can be calculated using equation 3:

$$df = k - 1 \quad (3)$$

$df = 7 - 1 = 6$

$Where\ k = Number\ of\ sides$

From the Chi-Square distribution table [31], the row corresponding to 6 degrees of freedom was used to locate the critical values at its corresponding significance values. The calculated test statistic was 95.8948 which is significantly greater than the highest value in the table for the smallest significance level (0.001). From this it can be inferred that the P value is less than 0.001. Considering the initial level of significance set for which P<0.05, the P-value 'indicates a statistically significant result' such that the null hypothesis can be rejected confidently [32]. This implies that there is very small probability that the spinner is random. This outcome was not desirable, but a critical analysis of the statistical distribution indicated that the frequency of side 1 was 1, which suggests that the data was skewed against fairness of getting side 1. Thus, the probability of getting side 1 was significantly lower than getting any other side.

Upon further investigation, there were some reasons suspected to be generating the statistical outlier for Side 1. First, since the spinner is designed to have equal sevenths and it was lasered to a high accuracy, unfairness in design was not due to the spatial geometry of the plate. Frictional resistance was investigated and the alignment of the motor and the plate and the structure can have enough clearance. Another reason suspected was runout, which is "how much one given reference feature or features vary with respect to another datum when the part is rotated 360° around the datum axis" [33]. This was mitigated by re-attaching the game plate to the motor using glue to prevent the attachment from loosening. After adjusting the assembly, three participants were asked to spin 100 times each. Duration of the activity was recorded.

Table 7: Mechatronic Spinner Practice Session with three Participant

User	Total Time (min)	No. of Spins	Time per Spin (s)
Researchers	59:27	200	17.84
Participant 1	28:50	100	17.30
Participant 2	29:29	100	17.69
Participant 3	29:11	100	17.51
			$\bar{x} = 17.585$

The Chi-Square Goodness of fit test was recomputed for the results in Table 7 using equations (1), (2) and (3). The result presented in Table 8 shows that P > 0.05. This indicates that the null hypothesis was rejected, and the alternate hypothesis accepted that the Mechatronic Spinner System generates significantly random numbers between 1 and 7. The average time for each spin is roughly between 17 seconds as presented in Table 8.

Table 8: Duration of the spin of the Mechatronic Spinner System

Sides	**Frequency for Participant 1**	**Frequency for Participant 2**	**Frequency for Participant 3**
1	20	6	28
2	10	21	3
3	25	8	21
4	22	18	16
5	10	17	8
6	7	14	9
7	6	16	15

7. Target Costing Analysis

One of the objectives of using LADRP methodology was to realise the Mechatronic Spinner System at a low cost. The cost was estimated using target costing approach to realise a device that costs less than £100 per unit. This cost did not take into consideration the fixed costs as the, labour, infrastructure and technology costs utilised at Loughborough University, including additive manufacturing, laser machine and mechatronics lab. The prices of the components were estimated based on the prices available on an e-Commerce online store [35]. The cost of a unit is £55.98 as presented in Table 8.

Table 8: Estimation of unit cost of the Game Spinner Syst

SN	Item	Cost/unit (£) (exc.VAT)	Quantity	Actual Cost (£)
1	3D Print Parts	0.02/g	328.21g	6.56
2	Laser Parts	100/hour	2 minutes	3.33
3	wires	24.90/100 meters	3 meters	0.747
4	push switch	3.06	1	3.06
5	flip switch	2.87	1	2.87
6	LED	2.11/5	1	0.422
7	10k ohm resistor	1.41/10	1	0.141
8	3.9k-ohm resistor	1.06/10	1	0.106
9	NPN Transistor	9.55/50	1	0.191
10	2.2k-ohm resistor	1.62/10	1	0.162
11	390-ohm resistor	1.06/10	1	0.106
12	Breadboard	3.24	1	3.24
13	Arduino	19.30	1	19.30
14	Brushed Motor	12.43	1	12.43
15	Battery Pack	1.29	1	1.29
16	AA Battery	10.15/20	4	2.03
Total				**£55.98**

8. Application of the Spinner for Co-Creativity, Co-Analysis and Co-Reflection.

There are many possible applications of the Mechatronic Spinner for individual creativity, analysis and reflection thinking. For more than one person, the Mechatronic Spinner can be used for co-creativity, co-analysis and co-reflection. Within the context of the Questelligence framework, thinking is the permutation and combination of items of the seven domains (Objective, Process, People, Place, Time, Specific and Reason) to create or understand meaning. Creativity is an integrative or a synthetic process whereas analysis is a differential process while reflection combines creativity and analysis. To the following are examples of applications of domain-based systems thinking, the following model is proposed.

6.1 Statistics and Probability Gamifications.

As demonstrated in Section 6, the spinner can be used to gamify statistics and probability lessons at High School. The Mechatronic Spinner can be spun, say 100 to 200 times, and the numbers or domains can be tallied and frequency table produced. Afterwards, the data generated can be used for teaching statistical mean, mode, median, standard deviation, variance analysis and experimental probabilities.

6.2 Problem-Solving for Systems, Projects, Products and Service Systems.

The Mechatronic spinner can be used to gamify creative problem-solving. As an example, after a spin, all the members can focus on the domain that showed and address all the issues in that domain. For example, in project management, if people domain turns up, the question can be identifying the people or stakeholders involved in the project and the communication strategy required to manage them to achieve the objectives of the project. For analytical problems, the focus of the co-analysis would be how different people or stakeholders were connected to the problem at hand. This can be integrated into the brainstorming process for creating or analysing complext systems, projects, products and services using domain-based thinking.

6.3 Storytelling.

Storytelling is a creative process and involves permutations and combinations to create frames of thoughts and arrange them in logical sequence. However, when people listen to the story, they listen analytically and sense the emotions behind the voice or text or images and interpret them within the context of their knowledge, culture and experiences. Domain-based thinking approach enables the creation of complicated and complex stories scaffolded on process domain or time domain. This can be done by creating systemic interactions between the domains of objectives, people, place, time, process with clear and specifics tailored through reason domains as demonstrated in the recent screenplay by Ogbonnaya [38], titled *The University Senate*. In this screenplay, Ogbonnaya created a complex interaction of different systems within the Nigerian setting including the education, judiciary, security, political, cultural, and social systems. The application of domain-based theory suggests that complex and complicated stories cannot be linearized as I can only be told as systems of systems withing specifics domain using scaffolds. Groups can also use the framework to create a method for co-creating stories for fun. Say, after a spin, they can take turns to create sentences that connect to the story being created and everyone can build on the ideas of others.

6.4 Problem-Solving.

The domain-based systems thinking was recently used to design project management module for MSc students at Loughborough University as a pedagogical framework to enhance metacognition of the theories and principles project management. The contents of the lectures were structured into lectures focusing on Objective domain of project management (why we do projects), People domain of project management (stakeholders involved in projects), Process domain of project management (methods for realizing projects), Time domain of project management (schedule tools and methods), Place domain of project management (environments where projects happens), Reason (logics and decisions on projects) and Specifics domains of project management (tailoring of domains of project) and Systems Integration domain of project management. Feedback from students indicated that the framework provided a metacognitive framework to think about project management processes as an approach to solve problems through creative, analytic and reflective thinking. Domain-based Project Risk Management was implemented, and Risk Register was categorised based on domains (Objective risks, People risks, Process Risks, Time Risks and Place Risks).

6.5 Cyclic Model for Thinking

Thinking remains elusive because it is an abstract process. Yet it affects the physical world and creates realities in systems around us both near and far. Thoughts can be linear or in systems, still thoughts emanate from the same source, which is the mind (natural or artificial). Here, systems such as artificial intelligent, including large language models (LLMs) are considered to “think” because they perform permutations and combinations. Human beings are biological systems, and the brain is the central processing unit that performs the permutations and combinations. Therefore, a common definition of thinking as mathematical process of permutation and combinations of items to create or understand logical patterns would eliminate misunderstanding of the ontology and epistemology of thinking. On the other hand, conceptualising thinking as a deterministic and mathematical process would enhance the understanding of metacognition and the science of mind and consciousness.

The cyclic mode of thinking in Figure 7 builds on what we already know about the hierarchy from data to wisdom. However, we propose a model which starts with thoughts as the cellular level and revelation at emergence level. Thoughts create data, whether in verbal forms, sounds, images, drawings, etc. Arrangement of data creates information.

Organised information creates knowledge whilst the rightful application of knowledge is a state of wisdom. Unlike knowledge, wisdom draws from explicit and tacit knowledge, experiences and skills to establish a systemic balance of diverse domains of a system and its environments to evidence wisdom. Wisdom can be understood because it is deeply embedded in knowledge. Revelation is at the level of intuition, and it may involve generating data from thought experiments using principles of polarity and combining the results of the thought experiments with wisdom, knowledge, information, data and thoughts to create awareness emerging from the status quo. Think of the valuable insights that can emerge from prompt engineering of LLM to output new and emergent knowledge or concept or insights. Apart from intuitions, predictions within the context of VUCA (volatility, uncertainties, complexity and ambiguity) can be classified at the level of revelational knowledge. Although revelation appears to be associated with religion and spirituality, our proposed model can explain the mechanisms of revelation as it sits above wisdom. The mind is a supercomputer with hidden computational processes. Consider the computational activity required to walk 3 miles to a Supermarket and buy five times and return home. Should you use e-commerce from home and avoid risks on the road and waste time; or take a walk to improve your health. Think about your thoughts as you decide and "see" how you are executing permutations and combinations to decide, plan actions, take actions and control your actions and environments.

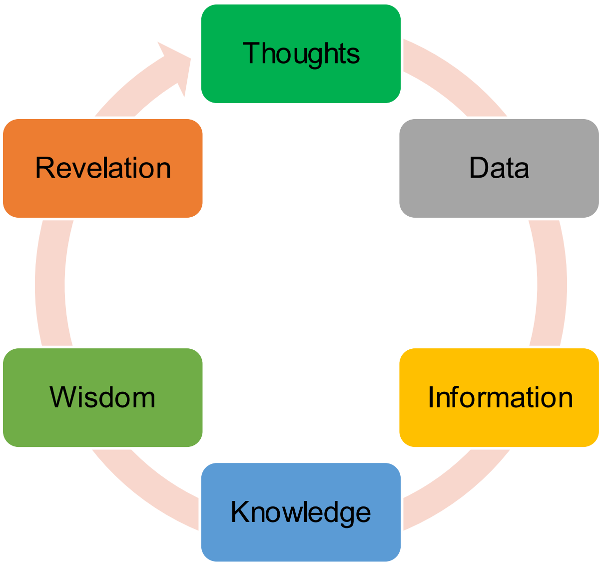


Figure 7: Cyclic Model of Thinking.

9. Conclusions

This research designed, developed, optimized, prototyped and tested a mechatronic-based spinner cable of generating randomness of the seven Questelligence domains. LADRP methodology was used to realise the prototype using design thinking and additive manufacturing. Pugh Matrix was useful in down selecting the conceptual design while the Morphology Matrix facilitated decision-making on the composition of the electronic subsystem. FMEA was used to identify and mitigate risks associated with efficient functioning of the Mechatronic Spinner. The case study showed that the Mechatronic Spinner System can generate random numbers which was very crucial in advancing the theory and practice of domain-based systems thinking for cognitive activities such as gamification, problem-solving, storytelling and teaching and learning. In this study, LLMs are considered as mind as they perform permutation and combinations like human mind and advancing thinking as a deterministic mathematical process could enhance co-creativity, co-analysis and co-reflections by humans and human-LLM fusion.

Supplementary Materials: NA

Author Contributions: Conceptualization, CO. ; methodology, CR.; software, CR.; validation, CO and CR; formal analysis, CR.; investigation, CR.; resources, CO.; data curation, CR.; writing—original draft preparation, CR.; writing—review and editing, C.; visualization, CR; supervision, CO.; project administration, CR.; funding acquisition, NA. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: NA

Acknowledgments: Thank you to the following staff at Loughborough University for their support to the project: Hussam Fraij, Peter Godfrey, Brijesh Gurav, Mark Capers and Tom Partington. The use of ChatGPT (https://openai.com/index/chatgpt/) to optimise codes generated is acknowledged.

Conflicts of Interest: The authors declare no conflicts of interest.

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